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ARMSTRONG LABORATORY

REAL-EAR ATTENUATION TESTING SYSTEM (RATS)

Nancy K. Allen

CREW SYSTEMS DIRECTORATE
BIODYNAMICS AND BIOCOMMUNICATIONS DIVISION

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

JAMES W. BRINKLEY, SES
Director
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13. ABSTRACT *(Maximum 200 words)*
This report provides a detailed description of the effort to reconstitute a sound attenuation measurement facility in compliance with ANSI S12.6-1984, "Method for the Measurement of the Real-Ear Attenuation of Hearing Protectors." The test methods used to check for compliance with the ANSI standard along with the results are fully documented. The equipment used in the automated measurement system and the sound attenuation measurement procedure using the system are also described.

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PREFACE

This work was accomplished in the Bioacoustics and Biocommunications Branch, Biodynamics and Bioengineering Division, Harry G. Armstrong Aerospace Medical Research Laboratory, Human Systems Division. This effort was accomplished in the Biocommunications Laboratory under Project 7231, Biomechanics in Aerospace Operations, Task 723121, Voice Communications, Work Unit 72312104, Bioacoustics and Biocommunications Research. Project Manager for this program was Nancy K. Allen. Technical support was provided by Richard McKinley, Mark Ericson, Denise West, and Angie Obert of the Bioacoustics and Biocommunications Branch and David Ovenshire, Larry Jacknin, and Ralph J. Logan of the Systems Research Laboratory.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Air Force personnel are often exposed to high levels of noise. One of the hazards of working in an intense noise environment is the risk of hearing impairment. To minimize the adverse effects of high noise levels, the Air Force has set policies outlined in AF Regulation 161-35, "Hazardous Noise Exposure" (1), to implement a hearing conservation and monitoring program for personnel working in hazardous noise environments.

There are three methods of protecting individuals from hazardous noise: providing engineering controls, administrative controls, and hearing protectors. Engineering controls provide noise control measures in the design of buildings, facilities, and weapon systems. When engineering controls are not feasible or do not provide the complete solution, administrative controls can be implemented to limit the work time in the noise environment. When engineering and administrative controls are not satisfactory solutions, then hearing protectors can provide noise attenuation to further reduce noise exposure and the associated risk of hearing damage.

Background

United States Air Force (USAF) scientific and technical resources are managed by primarily the Air Force Systems Command (AFSC). The Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) is a major contributor to the biotechnology research and development mission of the Human Systems Division (HSD), a component of AFSC. AAMRL conducts behavioral and biomedical research on human performance and tolerance in aerospace operations. The Biodynamics and Bioengineering Division (BB), one of five AAMRL divisions, studies the effects of physical forces - including mechanical, airborne, and vibrational - on humans. Bioacoustics and Biocommunications (BBA), a branch of BB, studies the effects of acoustic energy on humans.

Results of research conducted at AAMRL are relayed to the AFSC Surgeon General and the Base Bioenvironmental Engineers, and incorporated into AFR 161-35 to serve as guidelines in protecting government personnel from the adverse effects of hazardous noise associated with their duties. AAMRL scientists and engineers also provide field consultations to personnel regarding use of protective equipment and participate in accredited standards committees of the American National Standards Institute (ANSI) and the International Standards Organization (ISO).

One ongoing project is the non-routine measurement of the sound attenuation of hearing protectors and other items of personal equipment. Past measurements were taken in a small reverberation chamber that did not meet all the specifications in the current national standard measurement procedure, ANSI S12.6-1984 "Method for the Measurement of the Real-Ear Attenuation of Hearing Protectors" (2). The chamber was constructed as a room within a room, using six inch concrete for the floor, walls, and ceiling, separated from the outer structure by a six inch air gap. The chamber had a quadruple glazed plexiglas viewing window (2'-6" x 2'-6") and two acoustic sound doors (45" x 93" x 3").

The hearing protection measurement facility ambient noise levels were higher than permitted by ANSI S12.6 specifications at 125 to 500 Hz. Casual conversation in the adjacent control room was audible to subjects in the chamber. The hearing protector measurement system required an expert operator to control the noise level and frequency, evaluate each subject's test results, and analyze the data statistically. The manual collection and analysis of experimental data increased the possibility of human error in judgement and calculation.

This report provides a detailed description of the effort initiated to reconstitute the sound attenuation measurement facility by alteration of the acoustic chamber, compliance with the current national standards institute measurement methodology, and automation of the overall procedure.

Objectives

The objectives of the Real-ear Attenuation Testing System (RATS) were the following:

1. to provide a hearing protector measurement system that meets the specifications of ANSI S12.6-1984

2. to provide a fully automated measurement system that does not require an expert operator

3. to set up a flexible measurement system that can be used to measure hearing protector attenuation by the following methods:

    a. real-ear attenuation at threshold (REAT)
    b. physical-ear attenuation at threshold (PEAT)

4. to provide a data base management system for hearing protectors of various types:

    a. earplugs
    b. earmuffs
    c. communication headsets
    d. communication helmets
    e. active noise reduction units
    f. combinations of the above

5. to provide the following analyses of hearing protector attenuation data:

    a. mean attenuation and standard deviation at each third-octave band
    b. Air Force single number attenuation values
    c. Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) overall noise reduction rating (NRR)
    d. single number attenuation ratings using the high-medium-low (HML) method

6. to calculate the limiting duration of daily exposure to a given noise with or without a hearing protector

7. to provide printed documentation of hearing protector attenuation data

APPROACH

An isolated reverberation chamber was constructed within the existing reverberation chamber to provide a hearing protector measurement facility that complied with ANSI S12.6. A computer controlled measurement system was set up to eliminate the need for an expert operator. A user-friendly, menu-driven software program was developed to provide a flexible measurement system, provide a database management system, describe the hearing protector performance, and calculate the maximum permitted exposure time when wearing a certain hearing protector.

EXPERIMENTAL EQUIPMENT

Measurement Chamber

Extensive modifications were made on the existing reverberation chamber to meet the ANSI S12.6 requirements. Combining a diffuse sound field with very low ambient noise conditions required some special techniques.

The structural alterations made on the existing chamber are shown in Fig. 1. The inner sound door, plexiglas window, and metal plates of the wall opening were all removed. The window and wall openings were filled solid with concrete and then sealed with acoustic caulking.

Fig. 2 shows the mechanical alterations made on the chamber. The supply and return ventilation ducts were fitted with "Airsan" Compact Silencers to minimize the noise entering the chamber through the ventilation system. The two vent pipes were removed and capped at the floor and ceiling. The pneumatic thermostat (Pneu. Stat.) was relocated to the exterior of the chamber.

The electrical alterations made on the room are shown in Fig. 3. The existing receptacles remain for the new chamber. One electrical panel was abandoned and a patch panel was added to connect equipment inside the chamber to the equipment outside. Four incandescent light fixtures were removed and replaced with two fluorescent light fixtures inside the new chamber. The fire/smoke detector was relocated inside the new chamber.

Figs. 4 through 7 show the framing detail of the new chamber. No rigid connections were made between the new chamber frame and the existing room in order to reduce the transmission of noise from outside the chamber through vibrations of the walls. The four walls of the new chamber are made up of two double layers of drywall separated by a layer of fiberglass blanket insulation and 2" x 4" wood studs at the ceiling and floor. The floor of the old room is supported along the perimeter by 38 isodampers spaced 16" apart

on the center to absorb noise, vibration, and shock from noise sources outside of the chamber and from the operation of test equipment. The number and spacing of the isodampers were determined by the chamber dead load. The new floor is made up of 2" x 10" joists bridging across the isodampers and two layers of 3/4" plywood screwed to the joists. The ceiling is made up of two double layers of drywall separated by 2" x 10" joists and a layer of fiberglass blanket insulation. The edges of the new chamber and door frame are sealed with acoustic caulking. A new 3' x 7' sound door with a Sound Transmission Class (STC) of 47 was installed inside the chamber. The walls, floor, and ceiling were coated with three layers of epoxy paint. The new dimensions of the chamber are 14'8-1/4" x 9'6" x 8'7". The new work details of the measurement chamber are shown in Fig. 8.

Measurement System

The test apparatus required by ANSI S12.6-1984 for real-ear attenuation at threshold (REAT) testing includes a noise generator, a third-octave band filter set, calibrated attenuators, an on-off switch, loudspeaker(s), power amplifiers, and a head positioning device. A measurement system was set up as shown in Fig. 9. A microphone and a microphone preamplifier inside the measurement chamber are connected to a microphone amplifier, a digital voltmeter, and then interfaced with a Compaq 386 personal computer (PC) with color monitor and a Hewlett Packard (HP) Laserjet printer located outside the chamber. A subject response button located inside the chamber is connected to a control box outside the chamber. A set of eight Bose four inch diameter loudspeakers mounted one foot from and facing each corner inside the chamber and a set of two fifteen inch diameter Community Light & Sound (CLS) speakers mounted facing two adjacent corners at mid-height are connected to two separate channels of an amplifier. Each amplifier channel is connected to two Wilsonics programmable attenuators and then to the control box. The control box contains a pink noise generator, a third-octave band filter set, and a pulse generator. The control box and the PC are interfaced by an IEEE-488 bus. Equipment located inside the chamber is linked to the equipment outside through a patch panel. Equipment connected to the PC is controlled by a menu-driven software program which calibrates the microphone and programmable attenuators, collects, analyzes, stores, retrieves, and prints experimental data, and analyzes the performance of the measured hearing protection device.

Other equipment used in the measurement system includes a video camera, a subject chair, and a plumb bob reference to position the subject's head. A video monitor is located outside the chamber to observe the subjects. An intercom system consisting of a loudspeaker inside the chamber connected to an amplifier and a microphone outside the chamber allows the operator to speak to the subject. A set of headphones from the amplifier connected to the control box allows the operator to listen to the subject.

MEASUREMENTS - COMPLIANCE TO ANSI S12.6-1984

Measurement Chamber Test Space

ANSI S12.6-1984 requires that the measurement chamber test space meet specifications in the areas of ambient noise level, reverberation time, sound pressure level (SPL) uniformity about the subject's head position, and directionality of the sound field.

Ambient Noise

The equipment used to measure the ambient noise level of the measurement chamber test space is shown in Fig. 10. A Bruel & Kjaer (B&K) 4179 microphone and a B&K 266 microphone preamplifier inside the measurement chamber were connected to a B&K 2131 Digital Frequency Analyzer outside the measurement chamber.

The ambient noise levels measured inside the chamber with all the equipment in the measurement system turned on and the maximum ambient noise levels allowed by ANSI S12.6 are reported in Table 1. The ambient noise levels are all well below the specifications. Ambient noise levels measured with the flourescent lights turned on and with the air ducts uncovered exceeded the limits of ANSI S12.6 so measurements were made with the flourescent lights off, four 7.5 watt incandescent lights turned on to meet the specifications. Testing of subjects is conducted with the four 7.5 watt incandescent lights turned on and the flourescent lights off.

Table 1. Ambient Noise SPL (in dB) inside Measurement Chamber

Description	Octave Band Frequency (Hz)						
	125	250	500	1k	2k	4k	8k
ANSI S12.6	28	18	14	14	8	9	20
Measurement Chamber	17	11	12	7	7	4	3

Reverberation Time

The equipment used to measure the reverberation time in the chamber test space is shown in Fig. 11. A microphone and microphone pre-amplifier inside the measurement chamber were connected to a B&K 2131 Digital Frequency Analyzer which is connected to the input of a Sony 5206 Digital Audio Tape (DAT) recorder. A single impulse noise generated in the test chamber was recorded and then played back with the output of the DAT connected to the B&K 2131 and interfaced with an HP 9845 computer to calculate the reverberation time.

Reverberation time in the measurement chamber test space must be under 1.6 seconds at the third-octave bands ranging from 125 Hz to 8 kHz. Several reverberation measurements are shown in Table 2. The first set of data is the reverberation time in the chamber. The reverberation times exceeded the requirements at 250 to 1000 Hz. The addition of a piece of 4′ x 4′ acoustic wedged foam behind a 4′ x 6′ pressed hardboard propped against one wall brought the reverberation times in the chamber to specifications as shown in the second set of data in Table 2. The third set of data shows the

reverberation times in the completed chamber with the piece of foam behind the pressed hardboard cut down to 4′ x 4′ and painted with enamel paint mounted on a wall along with eight loudspeakers.

Table 2. Reverberation Time in Measurement Chamber in Seconds

Description	1/3-Octave Band Center Frequency (Hz)								
	125	250	500	1k	2k	3.15k	4k	6.3k	8k
Initial Chamber	-	1.78	1.73	1.69	-	-	-	-	0.73
Adjusted Chamber	1.55	0.97	1.45	1.56	-	-	-	-	1.13
Completed Chamber	0.53	0.94	1.46	1.45	1.39	1.47	1.54	1.19	0.99

Sound Pressure Level Uniformity

The uniformity of the test space sound field in an area 5 9 inches to the left, right, front, back, above, and below the subject's head are shown in Table 3. L-R indicates the SPL difference between the left and right positions and Max Diff indicates the maximum difference in SPL. The maximum L-R and the maximum difference in SPL allowed by ANSI S12.6 are 2 dB and 6 dB, respectively.

Table 3. Sound Pressure Level Uniformity in Measurement Chamber

1/3-Octave Band Center Frequency (Hz)	Left (dB)	Right (dB)	Front (dB)	Back (dB)	Up (dB)	Down (dB)	L - R (dB)	Max. Diff. (dB)
125	97.3	97.3	97.7	97.8	98.1	98.1	0.0	0.8
250	98.9	97.4	98.6	98.1	98.7	99.7	1.5	2.3
500	83.7	83.5	81.5	81.5	85.0	84.0	0.2	3.5
1k	76.8	76.7	77.1	77.2	79.0	78.0	0.1	3.3
2k	85.4	84.5	85.5	85.2	85.1	84.3	0.9	1.1
3.15k	81.9	80.4	81.1	80.6	80.9	80.2	1.5	1.7
4k	82.6	82.9	82.6	83.1	83.6	82.9	0.3	1.0
6.3k	85.9	86.0	85.6	84.9	86.4	86.2	0.1	1.5
8k	82.4	82.9	82.9	82.5	83.5	81.9	0.5	1.6

Sound Field Directionality

A cosine microphone was used to measure the sound field directionality inside the measurement chamber test space according to ANSI S12.6. Prior to the sound field directionality measurements, the cosine microphone was calibrated in an anechoic chamber to calculate the free-field rejection (front-to-side rejection). The results of the calibration are shown in Table 4. The amount of free-field rejection at each third-octave band determines the allowable random incidence field response at that band.

The directionality of the sound field in the chamber was measured from 500 Hz to 8 kHz by fifteen degree increments about three axes (x, y, and z) at the center of the subject's head position using the B&K 2131 Digital Frequency Analyzer. The readings obtained are shown in Tables 5 through 7. Table 8 shows that the maximum change in SPL is within the allowable random incidence field response at each third-octave band shown in Table 3.

The measurement chamber test space was measured for ambient noise level, reverberation time, SPL uniformity about the subject's head position, and directionality of the sound field. Data from the measurements demonstrate the chamber's compliance with ANSI S12.6.

Table 4. Calibration of Cosine Microphone

Third Octave Band Center Freq (Hz)	Maximum Reading V_{rms} (dB)	Maximum Reading Angle (deg)	Minimum Reading V_{rms} (dB)	Minimum Reading Angle (deg)	Free-Field Rejection (dB)	Allowable Random Incidence Field Response
125	58.2	0	46.6	80		
	58.3	175	45.4	275	11.6	3
250	77.2	0	57.4	85		
	78.0	175	52.4	275	19.8	5
500	79.8	0	58.9	90		
	79.8	180	53.4	275	20.9	5
1k	83.3	0	54.3	85		
	84.3	180	63.5	275	19.9	5
2k	86.9	0	64.6	90		
	87.4	180	62.8	275	22.3	5
3.15k	80.7	0	65.8	85		
	80.6	180	66.6	275	14.0	3
4k	76.3	0	64.0	80		
	76.0	180	66.5	275	9.5	3
6.3k	68.3	0	53.1	70		
	67.4	180	57.9	290	9.5	3
8k	64.4	0	45.6	60		
	69.7	175	46.8	300	17.6	4

Table 5. Sound Field Diffuseness in Measurement Chamber about x-axis (sound pressure level in dB)

Angle (Deg)	1/3-Octave Band Center Frequency (Hz)						
	500	1k	2k	3.15	4k	6.3k	8k
0	`64.9	61.4	`67.5	64.5	65.9	64.9	62.7
15	66.0	61.5	68.5	64.5	66.0	64.5	62.4
30	66.0	60.9	68.4	63.9	65.6	64.0	62.0
45	68.0	61.5	69.5	64.4	66.2	64.5	62.4
60	69.5	62.0	69.9	64.9	66.0	65.0	62.4
75	*69.9	62.5	69.9	64.7	65.9	64.9	62.5
90	69.5	62.5	*70.0	65.1	66.2	65.0	62.5
105	69.0	61.5	68.9	64.4	65.7	64.6	62.3
120	68.5	62.5	69.5	64.7	65.6	64.9	62.6
135	67.5	62.3	69.3	64.7	65.7	64.7	62.6
150	66.0	61.9	69.2	64.5	65.0	64.4	62.5
165	66.9	61.9	69.5	64.7	66.5	64.8	62.5
180	66.9	62.0	69.0	64.2	66.3	64.9	62.5
195	66.9	60.9	69.3	64.4	66.3	65.0	62.9
210	68.5	61.9	69.2	64.4	66.4	65.5	62.4
225	68.5	62.5	69.9	64.4	*66.9	65.3	63.0
240	69.8	61.4	69.3	64.5	65.9	65.4	62.6
255	69.0	62.5	69.4	64.5	66.2	65.1	62.6
270	68.5	`60.1	68.1	`62.9	`64.5	`63.9	`61.4
285	69.1	62.5	68.5	64.9	65.6	64.7	62.7
300	69.0	*62.9	69.9	*65.4	66.1	64.9	63.2
315	67.9	62.5	68.5	*65.4	66.2	*65.7	*63.9
330	66.3	61.9	68.1	63.9	65.4	65.1	62.9
345	66.0	62.0	67.6	64.4	65.9	65.1	63.0
360	`64.9	61.9	`67.5	64.2	65.3	65.0	62.6

*Maximum SPL

`Minimum SPL

Table 6. Sound Field Diffuseness in Measurement Chamber about y-axis (sound pressure level in dB)

Angle (Deg)	1/3-Octave Band Center Frequency (Hz)						
	500	1k	2k	3.15k	4k	6.3k	8k
0	73.5	71.9	80.6	78.2	81.9	89.3	88.7
15	74.8	72.5	80.2	78.1	81.8	89.2	88.7
30	74.3	73.1	80.4	78.2	81.6	89.5	88.7
45	74.1	74.0	79.6	77.7	81.7	89.3	88.6
60	74.1	74.3	79.9	ˆ77.4	ˆ81.4	89.3	88.6
75	75.1	74.2	79.6	77.8	81.6	89.3	88.9
90	74.4	*75.4	79.0	77.9	81.8	89.4	88.7
105	72.7	73.3	78.9	77.9	ˆ81.4	89.2	88.6
120	72.5	73.0	79.0	77.9	81.8	89.3	88.9
135	73.7	71.9	79.7	*78.4	81.9	*89.6	*89.0
150	73.0	71.5	ˆ78.8	77.6	81.7	89.1	88.6
165	72.5	ˆ70.6	79.7	77.9	82.0	89.4	88.7
180	ˆ71.9	70.7	79.9	77.6	81.9	89.2	88.5
195	72.8	71.0	79.7	77.8	81.7	89.5	88.7
210	73.0	72.7	79.6	ˆ77.4	81.5	89.4	88.7
225	75.5	72.8	80.3	78.1	81.8	89.3	ˆ88.4
240	75.0	74.1	79.9	78.3	*82.1	89.3	88.9
255	75.0	74.7	79.6	78.3	81.9	89.4	88.6
270	*75.7	74.2	79.0	*78.4	81.9	89.3	88.7
285	75.2	74.0	79.1	*78.4	82.0	89.3	88.5
300	74.9	72.7	79.3	78.2	81.7	89.5	88.7
315	74.7	72.1	79.4	78.2	81.7	89.1	88.6
330	74.2	71.6	80.2	78.0	81.8	89.4	88.9
345	74.4	71.3	*80.8	78.2	81.6	ˆ89.0	88.5
360	73.1	71.6	80.7	78.0	81.6	ˆ89.0	88.5

*Maximum SPL

ˆMinimum SPL

Table 7. Sound Field Diffuseness in Measurement Chamber about z-axis (sound pressure level in dB)

Angle (Deg)	1/3-Octave Band Center Frequency (Hz) 500	1k	2k	3.15k	4k	6.3k	8k
0	63.8	61.4	67.2	ˆ63.1	ˆ64.7	64.8	62.6
15	64.0	*62.0	67.9	63.5	65.3	65.0	62.6
30	63.0	61.9	68.7	63.8	65.3	ˆ64.7	62.6
45	63.5	61.9	69.7	63.9	65.5	65.0	62.6
60	63.0	61.7	70.1	64.0	6[illegible]6	65.1	62.7
75	63.3	61.4	70.0	64.1	65.5	64.9	ˆ62.1
90	63.8	61.7	*70.5	64.7	66.1	65.0	62.9
105	64.2	61.9	70.4	*64.9	65.7	64.9	62.7
120	64.7	61.8	69.5	64.7	65.7	65.0	62.7
135	64.9	61.9	68.9	64.7	65.3	65.0	62.6
150	64.8	60.9	68.3	64.7	65.0	64.9	62.7
165	65.8	60.9	67.9	64.4	65.5	ˆ64.7	62.6
180	*66.5	61.2	67.2	64.4	65.1	65.1	62.6
195	*66.5	*62.0	67.3	63.6	64.9	65.0	62.4
210	65.9	*62.0	67.5	63.2	65.3	ˆ64.7	62.6
225	65.1	62.0	69.0	64.2	65.5	64.9	62.5
240	63.9	61.9	68.5	64.3	65.6	64.9	62.4
255	62.3	61.9	68.1	64.0	65.5	65.1	62.3
270	ˆ61.7	*62.0	ˆ66.9	64.2	65.5	65.1	62.7
285	62.5	61.2	67.9	64.4	65.3	64.9	62.9
300	62.3	60.7	68.0	64.4	65.9	65.1	62.6
315	62.9	ˆ60.0	68.1	*64.9	65.7	65.0	62.5
330	63.0	60.8	67.7	*64.9	*66.2	*65.4	62.7
345	63.0	60.9	67.4	64.5	65.7	64.9	62.7
360	64.0	61.9	67.5	64.5	65.6	65.1	*63.0

*Maximum SPL

ˆMinimum SPL

Table 8. Maximum Sound Pressure Level Differences in dB (max - min) about x-, y-, and z-axes

		1/3-Octave Band Center Frequency (Hz)						
axis	condition	500	1k	2k	3.15k	4k	6.3k	8k
x	maximum	69.9	62.9	70.0	65.4	66.9	65.7	63.9
x	minimum	64.9	60.1	67.5	62.9	64.5	63.9	61.4
x	max - min	5.0	1.8	2.5	2.5	2.4	1.8	2.5
y	maximum	75.7	75.4	80.8	78.4	82.1	89.6	89.0
y	minimum	71.9	70.6	78.8	77.4	81.4	89.0	88.4
y	max - min	3.8	4.8	2.0	1.0	0.7	0.6	0.6
z	maximum	66.5	62.0	70.5	64.9	66.2	65.4	63.0
z	minimum	61.7	60.0	66.9	63.1	64.7	64.7	62.1
z	max - min	4.8	2.0	3.6	1.8	1.5	0.7	0.9
x,y,z	*max - min allowed	5.0	5.0	5.0	3.0	3.0	3.0	4.0

*Allowable random incidence field response from Table 3.

Measurement System

ANSI S12.6 requires that the measurement system test equipment meet certain specifications regarding the noise generator, third-octave band filters, attenuators, pulse generator, loudspeakers, head positioning device, and distortion.

The test signal source must be a uniform pink or white noise spectrum. A uniform pink noise signal source is generated within the control box. The test sounds must be produced using a third-octave band filter set whose bandwidths, band-edge frequencies, and other characteristics conform to the American National Standard Specifications for Octave, Half-Octave, and Third-Octave Band Filter Sets, S1.11-1966 (R1976), Class III. A third-octave band filter set is contained in the control box which generates the nine required test bands centered at 125, 250, 500, 1k, 2k, 3.15k, 4k, 6.3k, and 8k Hz.

The attenuators must have a range of 90 dB with steps of 2.5 dB or smaller. Four Wilsonics programmable attenuators are used, each having a range of 0 to 99 dB with 1 dB steps. Two attenuators in series are used at a time (one set for each set of loudspeakers) providing a range capability of 200 dB with 1 dB steps.

The test signal must be generated as a pulse with the following requirements (refer to Fig. 12):

- a rise time (B to C) and a fall time (E to G) of 20 ms to 50 ms
- an on-duration time (C to E) of at least 150 ms
- a repetition rate (F to I and I to J) of 200 ms

- a signal output level in the off phase of at least 20 dB below the maximum level reached during the on phase of each repeated pulse

- a smoothly varying sound pressure level without discontinuities between B and C and between E and G.

The pulse generator in the control box has a rise and fall time of 50 ms, an on-duration time of 200 ms, a repetition rate of 200 ms, a signal output level in the off phase of 79.5 dB below the maximum level reached during the on phase of each repeated pulse, and a continuous variation in sound pressure level during the rise and fall of the pulse signal.

The loudspeakers must provide a sound field at each test band in which the sound pressure level (SPL) can be varied from 10 dB above the occluded threshold of hearing to 10 dB below the unoccluded threshold of hearing (the lower level may be calculated on the basis of electrical calibration). A set of two fifteen inch diameter Community Light & Sound loudspeakers generates test signals at 125 and 250 Hz, and a set of eight 4.5 inch diameter Bose speakers generates test signals at 500 to 8000 Hz. Table 9 shows the maximum and minimum SPL required by the standard and how they were obtained. The maximum SPL (row 7) is the sum of the normal threshold of hearing obtained from ISO/R 226-1961 (4) (row 1), the worst hearing allowed for the test subjects (row 2), the highest sound attenuation expected from double hearing protection (row 3), and the 10 dB above the occluded threshold of hearing specified by the standard (row 4). The minimum SPL (row 8) is the normal threshold of hearing minus the best hearing allowed for test subjects (row 5) minus the 10 dB below the unoccluded threshold of hearing required by the standard (row 6). The maximum amount of attenuation the Wilsonics attenuators must provide to obtain the minimum SPL is shown in row 9.

Table 10 compares the maximum SPL required with the actual SPL attained and the maximum attenuation required with the maximum attenuation possible. The table also shows the amplifier and attenuator settings used to attain the maximum SPL without distorting the signal. The maximum SPL was measured on a B&K 2131 Digital Frequency Analyzer (see Fig 13 for block diagram). All the maximum SPLs are above the required levels except at 250 Hz and 2 kHz which are within 1 dB of the required maximums. The maximum attenuation possible is the difference between the 200 dB attenuation capability of two Wilsonics attenuators and the attenuator setting (row 4) used to attain the maximum SPL without distortion.

The entire measurement system up to the loudspeaker terminals must produce less than 5% total harmonic distortion with the system set at maximum gain and the test signal being a discrete pure tone. An external signal source was connected to the control box to generate the pure tones and the loudspeakers were replaced by a 4.2 ohm, 50 W resistor. The distortion was measured on an HP 8903A Audio Analyzer and was verified to be well below 5% at all nine test bands. Figure 14 shows the block diagram of the distortion test and Table 11 shows the results of the test.

Table 9. Required Maximum and Minimum SPL Generated by Loudspeakers

Description	1/3-Octave Band Center Frequency (Hz)								
	125	250	500	1k	2k	3.15k	4k	6.3k	8k
1. Normal threshold of hearing (dB)	21.4	11.2	6	4.2	1	-2.9	-4	4.6	15.3
2. Worst hearing threshold level (dB)	20	20	20	20	20	20	20	20	20
3. Maximum attenu-ation (dB)	48	47	52	51	59	64.4	67	61.1	53
4. SPL above occluded threshold (dB)	10	10	10	10	10	10	10	10	10
5. Best hearing threshold level (dB)	10	10	10	10	10	10	10	10	10
6. SPL below un-occluded threshold (dB)	10	10	10	10	10	10	10	10	10
7. Maximum SPL (dB) Required (1+2+3+4)	99.4	88.2	88	85.2	90	91.5	93	95.7	98.3
8. Minimum SPL (dB) Required (1 - 5 - 6)	1.4	-8.8	-14	-15.8	-19	-22.9	-24	-15.4	-4.7
9. Maximum Attenu-ation Required (dB)	98.0	97.0	102.0	101.0	109.0	114.4	117.0	111.1	103.0

Table 10. Comparison of Required with Actual Maximum and Minimum SPL Generated by Loudspeakers

Description	1/3-Octave Band Center Frequency (Hz)								
	125	250	500	1k	2k	3.15k	4k	6.3k	8k
1. Required Maximum SPL (dB)	99.4	88.2	88.0	85.2	90.0	91.5	93.0	95.7	98.3
2. Actual Maximum SPL (dB)	99.9	88.0	90.4	86.3	89.4	92.3	96.2	105.5	104.2
3. Amplifier Setting	38	38	35	35	35	35	35	35	35
4. Attenuator Setting	0	22	8	19	19	12	8	3	0
5. Required Maximum Attenuation (dB)	98.0	97.0	102.0	101.0	109.0	114.4	117.0	111.1	103.0
6. Actual Maximum Attenuation (dB)(200 dB-#4)	200	178	192	181	181	188	192	197	200

Table 11. Total Harmonic Distortion of Measurement System

1/3-Octave Band Center Frequency (Hz)	% Distortion
125	0.12
250	0.40
500	0.04
1k	0.56
2k	0.67
3.15k	0.67
4k	0.47
6.3k	0.39
8k	0.45

The loudspeakers must generate a sound field at each test band that is 5 dB down from the maximum level for adjacent third-octave bands and 30 dB

down for the third-octave bands one octave or more removed from the center frequency. This was verified by measuring the test signal at each third-octave band on the B&K 2131 Digital Frequency Analyzer. Figure 13 shows the block diagram of the test setup and Table 12 shows the results of the test.

Table 12. Loudspeaker Distortion (Sound Pressure Level in dB)

	1/3-Octave Band Center Frequency (Hz)								
Description	125	250	500	1k	2k	3.15k	4k	6.3k	8k
1. left octave band	54.0	35.7	47.6	37.2	46.0	54.3	54.4	64.0	62.4
2. left adjacent band	86.4	76.4	83.5	75.1	83.0	84.7	86.6	99.7	98.7
3. center band	99.9	88.0	90.4	86.3	89.4	92.3	96.2	105.5	104.2
4. right adjacent band	93.7	82.9	83.7	80.1	78.9	80.0	85.8	92.4	83.9
5. right octave band	69.2	45.1	56.2	44.4	42.4	52.5	54.0	53.5	51.0
#3 - #2	13.5	11.6	6.9	11.2	6.4	7.6	9.6	5.8	5.5
#3 - #4	6.2	5.1	6.7	6.2	10.5	12.3	10.4	13.1	20.3
ANSI S12.6 Minimum	5	5	5	5	5	5	5	5	5
#3 - #1	45.9	52.3	42.8	49.1	43.4	38.0	41.8	41.5	41.8
#3 - #5	30.7	42.9	34.2	41.9	47.0	39.8	42.2	52.0	53.2
ANSI S12.6 Minimum	30	30	30	30	30	30	30	30	30

A head-positioning device must be used to allow the subject to maintain her/his head in a constant position without transmitting any vibrations to the subject's head or presenting a reflective or absorptive surface that alters the sound pressure level at the subject's ears. A plumb bob suspended at the subject's nose is used as a reference point for the subject's head position.

The measurement system equipment was tested and verified for compliance with ANSI S12.6 regarding the noise generator, third-octave band filters, attenuators, pulse generator, loudspeakers, head positioning device, and distortion.

MEASUREMENT PROCEDURE

The measurement procedure for hearing protector attenuation complies with ANSI S12.6. Potential subjects are given preliminary hearing tests, which aid in selecting a minimum of ten subjects qualified to participate in the procedure. Selectees are given an initial fitting of the hearing protector device to be measured, instructed on the measurement procedure, and given a real-ear attenuation at threshold (REAT) test from which attenuation data is collected

and analyzed.

Subjects are first screened by a hearing test given on a standard audiometer to ascertain that their hearing threshold levels are no better than -10 dB and no worse than 20 dB at all frequencies. Afterwards, the subjects are trained for REAT testing by taking three successive unoccluded threshold tests on the automated measurement system. A threshold measurement is obtained for each of the nine third-octave bands centered at 125, 250, 500, 1k, 2k, 3.15k, 4k, 6.3k, and 8k Hz. Measurements are obtained by the Bekesy tracking method, a method of adjustment whereby the subject controls the varying level of the test signal with a hand-held switch. An initial signal at suprathreshold (approximately 40 dB above the normal hearing threshold level) is presented to the subject who pushes the subject response button when the signal is audible (reducing the level) and releases the button when the signal is inaudible (increasing the level). A threshold is the average value of a minimum of six responses from the subject at a particular test signal. The values of the subject's responses are required to have no peak lower than any valley and no peak to valley range greater than 20dB. Threshold tracking is continuous until it conforms to the requirements or until two minutes have elapsed, whichever comes first. When the threshold measurements are completed, the six values (three peaks and three valleys) are averaged for a single threshold level. If an acceptable measurement is not obtained within the allotted time, it can be repeated after testing all other bands.

The three successive unoccluded threshold levels are checked to ascertain that the threshold variability is no greater than 5 dB at all frequencies. Subjects passing the preliminary screening consisting of the hearing and the unoccluded threshold tests are selected for REAT testing.

Subjects selected for REAT testing are instructed on the measurement procedure and given the instruction sheet shown in Appendix 2 to read. The hearing protector to be measured is provided to the subject with fitting instructions to allow each subject to develop practice and familiarity with the fit. Each subject dons the hearing protection device and is then tested using the REAT method for a minimum of three trials.

Each trial of the REAT method consists of an occluded (with the hearing protector on) and an unoccluded (open ear, no hearing protector) threshold of hearing test. The occluded and unoccluded threshold test methods are identical, using the Bekesy method to measure the subject responses to the nine third-octave test bands, as previously explained. The attenuation of the hearing protector is the difference between the occluded and unoccluded threshold levels of hearing.

The measurements obtained from the subjects are controlled and checked for compliance to ANSI S12.6 by the computer software. Pressing and releasing the subject response button changes the attenuator to increase and decrease the sound pressure level of the test signal. The third-octave band filters are also under computer control, switching to the next test band when a measurement is completed. A step-by-step list of instructions for testing the subjects using the software is shown in Appendix 3. Upon completion of the hearing protector attenuation data collection, the software conducts an analysis on the data as described in the Data Analysis section.

DATA ANALYSIS

When all the data for a hearing protection device is collected, it is calculated for mean attenuation, standard deviation, and several single number attenuation values.

A statistical analysis of the data consists of the mean attenuation and standard deviation of the device at each test signal. A calculation of the mean attenuation minus two times the standard deviation is also included to represent the minimum attenuation obtained by 97.5% of the wearers, allowing for variations in the fit of the hearing protector and the sizes of wearers' heads.

The attenuation data is also used to calculate several single number attenuation values, including the attenuation at five C-A values for fifty aircraft noises, the overall noise reduction rating (NRR), and attenuation rating at high, medium, and low frequencies (HML technique).

The C-A value is the C-weighted overall sound pressure level minus the A-weighted overall sound pressure level (dBC-dBA) and is described in AFR 161-35, "Hazardous Noise Exposure" (1). The higher the C-A value, the more low frequency contributions there are to the sound pressure level. The single number attenuation values for the five C-A ranges of -2 to 0, 1 to 3, 4 to 7, 8 to 12, and 13 to 19 are calculated by performing a linear regression on the noise level under the hearing protector at each third-octave band when exposed to fifty Air Force aircraft noises. See Appendix 1 for the method of calculation.

The calculation of the noise reduction rating (NRR) is described in the EPA (1979) "Noise Labeling Requirements for Hearing Protectors" (3). The NRR gives a single number rating of a hearing protector with mean attenuation minus two times the standard deviation in a hypothetical 100 dB noise across the spectrum (125 - 8000 Hz).

The attenuation rating using the high-medium-low (HML) method is described in "Three methods for calculating the attenuation index of an hearing protector - A presentation and a Comparison" by Rune Lundin (5). Calculations are based on eight reference noise spectra based on the 100 National Institute of Occupational Safety and Health (NIOSH) noises (7). Attenuation indices are calculated for each noise and a linear function is established by linear regression.

The software will also calculate the limiting daily noise exposure time allowed for a hearing protective device in a given level of noise as described in AFR 161-35. The noise can be entered as sound pressure level (dB) across the frequency spectrum or as overall noise level in dBA or dBC. The limiting exposure duration can be calculated for an individual wearing a hearing protector on file in the database, another hearing protector given its noise reduction rating, and for an individual not wearing a hearing protector. The actual noise exposure is then calculated in overall dBA and used to calculate the limiting daily noise exposure duration as described in AFR 161-35.

CONCLUSION

The objective of developing a facility to permit measuring hearing protector attenuation according to ANSI S12.6 was accomplished by building a measurement chamber and setting up a measurement system that comply with the standard as reported in the Measurements section. The chamber and system satisfied all of the specifications.

The other objectives listed in the Objectives section were accomplished by developing a software program on a personal computer to control the measurement system and perform various other functions with the data collected. The measurement system is controlled by a personal computer, eliminating the need for an expert operator. The software also calculates the mean and standard deviation of the attenuation data collected, various single number attenuation values, and the limiting duration of daily exposure to a given noise with or without the hearing protector. A database stores the data collected along with the calculations for various hearing protector types. The measurement system is presently used to measure hearing protector attenuation utilizing the REAT method.

Appendix 1. Method for the Calculation of C-A Attenuation Values

Definition of variables:

f = *midfrequency in Hz of octave bands*

A_f = *A-weighting in dB at f (see Table A1.1.)*

C_f = *C-weighting in dB at f (see Table A1.1.)*

N_f = *sound pressure level (SPL) in dB at f*

Att_f = *attenuation of hearing protector minus two standard deviations at f*

$$N_A = 10\log\left(\sum_{f=63}^{8k} 10^{0.1(N_f + A_f)}\right)$$

= *A-weighted SPL in dB*

$$N_C = 10\log\left(\sum_{f=63}^{8k} 10^{0.1(N_f + C_f)}\right)$$

= *C-weighted SPL in dB*

$$N_{HP} = 10\log\left(\sum_{f=125}^{8k} 10^{0.1(N_f + A_f - Att_f)}\right)$$

= *A-weighted SPL under hearing protector in dB*

$Att_I = N_a - N_{HP}$

= *attenuation index* for *hearing protector*

$N_{C-A} = N_C - N_A$

Table A1.1. C- and A-weighting.

Third-Octave Band f (Hz)	A-weighting A_f (dB)	C-weighting C_f (dB)
63	-26.1	-0.8
125	-16.2	-0.2
250	-8.6	0
500	-3.3	0
1000	0	0
2000	1.2	-0.2
4000	1	-0.8
8000	-1.1	-3

The attenuation indices (Att_I) for the 50 aircraft noises in Table A1.2 with the N_{C-A} values of the corresponding noises are calculated and used to establish a linear function by linear regression.

$$m = slope = \frac{50\sum_{i=1}^{50}(N_{C-A})_i - \sum_{i=1}^{50}(N_{C-A})_i \sum_{i=1}^{50}(Att_I)_i}{50\sum_{i=1}^{50}(N_{C-A})_i^2 - (\sum_{i=1}^{50}(N_{C-A})_i)^2}$$

$$a = y\text{-}intercept = \frac{50\sum_{i=1}^{50}(N_{C-A})_i^2 \sum_{i=1}^{50}(Att_I)_i - \sum_{i=1}^{50}(N_{C-A})_i \sum_{i=1}^{50}(N_{C-A})_i (Att_I)_i}{50\sum_{i=1}^{50}(N_{C-A})_i^2 - (\sum_{i=1}^{50}(N_{C-A})_i)^2}$$

C-A				
-2 to 0	1 to 3	4 to 7	8 to 12	13 to 19
a - m	a + 2m	a + 5.5m	a + 10m	a + 16m

Table A1.2. Fifty Aircraft Noises (in dB).

1/3-Octave Band (Hz)	63	125	250	500	1k	2k	4k	8k
1	83	94	89	97	96	96	96	88
2	92	97	99	107	106	106	104	102
3	102	101	102	104	104	104	110	117
4	83	83	91	91	88	90	94	101
5	78	72	73	75	70	69	69	66
6	82	81	86	83	84	82	76	75
7	80	86	88	88	85	83	80	78
8	81	89	81	88	94	96	93	95
9	88	89	89	87	83	83	82	77
10	104	105	102	95	94	104	103	101
11	89	91	87	81	73	68	60	55
12	101	104	109	108	103	101	97	103
13	103	105	105	104	100	99	107	107
14	101	94	90	89	79	77	77	73
15	101	94	95	95	88	84	84	81
16	104	92	94	93	85	81	80	76
17	101	109	101	94	89	86	82	79
18	108	101	91	88	85	83	80	78
19	111	98	97	96	98	95	92	92
20	92	104	95	95	101	93	91	86
21	101	98	97	98	99	96	94	89
22	77	95	88	95	101	97	99	89
23	97	102	101	107	104	100	95	95
24	91	94	102	105	104	103	100	94
25	83	98	92	93	92	90	85	83
26	90	89	94	97	95	99	99	94
27	81	92	78	81	82	81	81	73
28	107	108	109	109	107	108	108	107
29	101	108	106	95	88	85	83	80
30	98	104	104	103	100	99	98	94
31	111	99	96	89	82	82	84	87
32	84	80	79	72	66	66	63	55
33	116	112	112	105	99	95	90	88
34	100	108	103	102	96	92	87	82
35	111	100	102	98	94	92	87	80
36	103	106	101	99	93	90	86	80
37	111	112	107	107	105	106	104	99
38	101	105	103	103	98	95	91	85
39	98	108	92	89	84	82	78	74
40	104	99	98	95	92	91	85	88
41	105	98	98	93	90	88	84	85
42	103	104	97	95	89	85	82	80
43	103	114	109	99	93	87	82	75
44	96	94	90	96	95	97	99	98
45	93	110	111	111	95	92	89	84
46	101	112	118	114	106	105	101	96
47	98	108	115	112	99	95	92	90
48	85	90	93	92	90	89	84	80
49	86	79	73	77	73	72	68	62
50	86	91	94	95	92	84	84	90

Appendix 2. Measurement Procedure Instruction Sheet

INFORMATION FOR SUBJECTS PARTICIPATING IN ATTENUATION STUDIES

Overview of experiment

These experiments are designed to measure the noise reducing capabilities of hearing protection devices. You will be asked to attend to very quiet levels of noise in conditions with and without hearing protectors. There will be an instructional and training period in which we will teach you how to respond appropriately. A typical day of participation will consist of three trials with a trial consisting of a run with and without hearing protection. Each daily participation will last approximately three to four hours with appropriate rest periods between trials. The following section contains the instructions that you will need to follow.

Instructions

In these listening measurements, the test sound will get louder or softer depending on the position of a response button which you will control. The sound will grow softer and softer when the button is depressed and it will grow louder and louder when the button is released. To begin, you will hear the test signal, which will change from time to time during the test. Hold the response button down while you hear the signal growing softer,then release the button as soon as the sound disappears. When you hear the sound again, hold down the button as before. Repeat this "on - off" procedure until the test is finished.

Appendix 3. RATS Software Operating Instructions

The software used to run the measurement system is menu-driven. The following is a list of instructions to calibrate the measurement system, run an experiment, and obtain a final printout of results from Harvard Graphics.

1. Turn on the following equipment in the measurement system:

   a. Compaq 386 PC
   b. control box
   c. Wilsonics attenuators
   d. amplifiers
   e. video camera and monitor
   f. HP laserjet printer
   g. digital voltmeter
   h. microphone power supply

2. Type the following commands on the PC to load and run the software:
   a. cd hp_basic <return>
   b. basic <return>
   c. load "rats" <return>
   d. <F3> (run)

3. The following steps allow you to calibrate the system:

   a. Choose option 1 (calibrate microphone and system) from the main menu.
   b. Choose option 1 (calibrate microphone and system from the calibration menu).
   c. When asked if you want to calibrate the microphone type "y" to do so or "n" to go on to system calibration (go to e).
   d. Follow the directions as prompted when asked for the microphone to be used and to put on and take off the microphone calibrator.
   e. When asked if you want to calibrate the system type "y" to do so or "n" to go back to the calibration menu (skip f).
   f. Follow directions as prompted. The SPL values for the attenuator and frequency settings are displayed. You may obtain a printout and view the graphs of the SPL values.

4. The following allows you to set up the parameters of a new experiment, such as, number of subjects, trials, models of hearing protectors, and starting frequency of the test signal:

   a. Choose option 2 (collect data) from the main menu.
   b. Choose option 2 (new data) from the data collection menu.
   c. Choose option 1 (set up a new experiment) from the new data collection menu.
   d. Enter the data as prompted.

e. When asked if the information is correct type "y" to save it or "n" to reenter information.
f. When asked if you would like to continue testing with the experiment type "y" to do so (go on to #6) or "n" to return to the previous menu.

5. The following allows you to collect data from a current experiment that has already been set up:

a. Choose option 2 (collect data) from the main menu.
b. Choose option 2 (new data) from the data collection menu.
c. Choose option 2 (continue a current experiment) from the new data collection menu.
d. The parameters of the last experiment that was run are displayed.
e. When asked if you want to continue with this experiment type "y" to do so (go to #6) or "n" to see a list of current experiments to choose from.
f. Type in the number of the experiment you wish to run. The parameters of the experiment are displayed. Go to e.

6. The following allows you to run the current experiment you have chosen:

a. Enter the information as prompted (subject number, name, age, sex, occluded or unoccluded threshold test).
b. If this is the first trial, three *unoccluded thresholds* may be tested for training of the subject or for comparison to experimental data.
c. If threshold tests need to be repeated, you are informed of the fact and asked if you wish to do so at that time.
d. At the end of one subject's run, a printout of the subject's responses, average occluded and unoccluded thresholds, and attenuation is generated as shown in Appendix 4.
e. When asked if you wish to test another subject, type "y" to do so (go to a) or "n" to return to the previous menu.

7. When the experiment is completed and all subjects have been tested, then a printout of the measurement results with a statistical analysis is generated as shown in Appendix 5.

8. Attenuation data already collected from other experiments may also be entered into the database by the following steps:

a. Choose option 2 (collect data) from the main menu.
b. Choose option 1 (old data) from the data collection menu.
c. Choose option 1 (create or edit a data file) from the old data collection menu.

d. Enter the information as prompted.
e. When asked if the information is correct type "n" to reenter information or "y" to save it.

9. A final report of the attenuation of a hearing protector model along with a statistical and noise analysis may be obtained from Harvard Graphics by the following steps:

a. Choose option 3 (print results/calculate limiting noise exposure) from the main menu.
b. Choose option 1 (print results and noise analysis of hearing protector) from the print results menu.
c. Select the type and model of hearing protector desired.
d. Choose option 4 to exit the program.
e. Press <Ctrl> and <F10> simultaneously to exit HP Basic.
f. Type cd.. <Enter>.
g. Type cd hg <Enter>.
h. Type macro <Enter>.
i. Type hg <Enter>.
j. Press <Alt> while you type 0 (zero).
k. Select P to play back a macro.
l. Type in "rats" as the title of the macro.
m. A printout is generated from Harvard Graphics with a blank space in the upper right corner provided for a scanned photograph of the hearing protector as shown in Appendix 6.
n. To exit Harvard Graphics type E.
o. Type cd ..
p. Follow instruction number 2 to get back in the RATS software program

10. The limiting duration of daily noise exposure can be calculated for a hearing protector on file or another hearing protector by the following steps:

a. Select option 3 (print results/calculate limiting noise exposure) from the main menu.
b. Select option 2 (calculate limiting duration of noise exposure).
c. Enter the information as prompted for level of noise exposure and hearing protector model or NRR.

Appendix 4. Sample Printout Generated for a Trial

```
7 Jul 1968
08:12:45 TO 08:29:01
SUBJECT  TRIAL  NAME                                                    SEX  AGE
   1       1    JOHN DOE                                                  M   28
EARMUFF  DAVID CLARK MODEL 10A RIBBED

                    FREQUENCY (Hz)
   125   250   500  1000  2000  3150  4000  6300  8000  TEST 1KHz
OCCLUDED THRESHOLD VALUES
    38    34    39    33    46    41    41    41    39
    32    28    33    26    40    35    35    35    33
    38    34    39    33    46    41    41    41    39
    32    28    33    26    40    35    35    35    33
    38    34    39    33    46    41    41    41    39
    32    28    33    26    40    35    35    35    33

AVERAGE OCCLUDED THRESHOLD
    35    31    36    29    43    38    38    38    36    29


UNOCCLUDED THRESHOLD VALUES
    25    14     9    -1     4     0    -1     8    18
    19     8     3    -7    -2    -6    -7     2    12
    25    14     9    -1     4     0    -1     8    18
    19     8     3    -7    -2    -6    -7     2    12
    25    14     9    -1     4     0    -1     8    18
    19     8     3    -7    -2    -6    -7     2    12

AVERAGE UNOCCLUDED THRESHOLD
    22    11     6    -4     1    -3    -4     5    15    -4


ATTENUATION
    13    20    30    34    42    41    42    33    21
```

Appendix 5. Sample Printout Generated Upon Completion of an Experiment

EARMUFF DAVID CLARK MODEL 10A RIBBED
MANUFACTURER: DAVID CLARK COMPANY INC.
366 PARK AVE
WORCESTER MASS. 01610
WEIGHT: 12 oz
COMMENTS:

1/3 OB (Hz)

	125	250	500	1000	2000	3150	4000	6300	8000
MEAN ATTENUATION	13	20	30	33	42	41	42	33	21
STANDARD DEVIATION	5.00	4.00	5.00	5.00	6.00	5.00	6.00	8.00	7.00
MEAN ATTENUATION - 2 x STANDARD DEVIATION	3.00	12.00	20.00	23.00	30.00	31.00	30.00	17.00	7.00

METHOD: ANSI Z24.22-1957
NUMBER OF SUBJECTS: 10
NUMBER OF TRIALS PER SUBJECT: 3
PRINCIPAL INVESTIGATOR: CHARLES NIXON
START DATE OF EXPERIMENT: 1968
END DATE OF EXPERIMENT: 1968

			1/3 OCTAVE BAND (Hz)								
			125	250	500	1000	2000	3150	4000	6300	8000
SUB	TRL	DESC									
1	1	C	35	31	36	29	43	38	38	38	36
1	1	O	22	11	6	-4	1	-3	-4	5	15
1	1	A	13	20	30	33	42	41	42	33	21
1	2	C	35	31	36	29	43	38	38	38	36
1	2	O	22	11	6	-4	1	-3	-4	5	15
1	2	A	13	20	30	33	42	41	42	33	21
1	3	C	35	31	36	29	43	38	38	38	36
1	3	O	22	11	6	-4	1	-3	-4	5	15
1	3	A	13	20	30	33	42	41	42	33	21
2	1	C	35	31	36	29	43	38	38	38	36
2	1	O	22	11	6	-4	1	-3	-4	5	15
2	1	A	13	20	30	33	42	41	42	33	21
2	2	C	35	31	36	29	43	38	38	38	36
2	2	O	22	11	6	-4	1	-3	-4	5	15
2	2	A	13	20	30	33	42	41	42	33	21
2	3	C	35	31	36	29	43	38	38	38	36
2	3	O	22	11	6	-4	1	-3	-4	5	15
2	3	A	13	20	30	33	42	41	42	33	21
3	1	C	35	31	36	29	43	38	38	38	36
3	1	O	22	11	6	-4	1	-3	-4	5	15
3	1	A	13	20	30	33	42	41	42	33	21
3	2	C	35	31	36	29	43	38	38	38	36
3	2	O	22	11	6	-4	1	-3	-4	5	15
3	2	A	13	20	30	33	42	41	42	33	21
3	3	C	35	31	36	29	43	38	38	38	36
3	3	O	22	11	6	-4	1	-3	-4	5	15
3	3	A	13	20	30	33	42	41	42	33	21
4	1	C	35	31	36	29	43	38	38	38	36
4	1	O	22	11	6	-4	1	-3	-4	5	15
4	1	A	13	20	30	33	42	41	42	33	21
4	2	C	35	31	36	29	43	38	38	38	36
4	2	O	22	11	6	-4	1	-3	-4	5	15
4	2	A	13	20	30	33	42	41	42	33	21
4	3	C	35	31	36	29	43	38	38	38	36
4	3	O	22	11	6	-4	1	-3	-4	5	15
4	3	A	13	20	30	33	42	41	42	33	21
5	1	C	35	31	36	29	43	38	38	38	36
5	1	O	22	11	6	-4	1	-3	-4	5	15
5	1	A	13	20	30	33	42	41	42	33	21
5	2	C	35	31	36	29	43	38	38	38	36
5	2	O	22	11	6	-4	1	-3	-4	5	15
5	2	A	13	20	30	33	42	41	42	33	21

5	3	C	35	31	36	29	43	38	38	38	36
5	3	O	22	11	6	-4	1	-3	-4	5	15
5	3	A	13	20	30	33	42	41	42	33	21
6	1	C	35	31	36	29	43	38	38	38	36
6	1	O	22	11	6	-4	1	-3	-4	5	15
6	1	A	13	20	30	33	42	41	42	33	21
6	2	C	35	31	36	29	43	38	38	38	36
6	2	O	22	11	6	-4	1	-3	-4	5	15
6	2	A	13	20	30	33	42	41	42	33	21
6	3	C	35	31	36	29	43	38	38	38	36
6	3	O	22	11	6	-4	1	-3	-4	5	15
6	3	A	13	20	30	33	42	41	42	33	21
7	1	C	35	31	36	29	43	38	38	38	36
7	1	O	22	11	6	-4	1	-3	-4	5	15
7	1	A	13	20	30	33	42	41	42	33	21
7	2	C	35	31	36	29	43	38	38	38	36
7	2	O	22	11	6	-4	1	-3	-4	5	15
7	2	A	13	20	30	33	42	41	42	33	21
7	3	C	35	31	36	29	43	38	38	38	36
7	3	O	22	11	6	-4	1	-3	-4	5	15
7	3	A	13	20	30	33	42	41	42	33	21
8	1	C	35	31	36	29	43	38	38	38	36
8	1	O	22	11	6	-4	1	-3	-4	5	15
8	1	A	13	20	30	33	42	41	42	33	21
8	2	C	35	31	36	29	43	38	38	38	36
8	2	O	22	11	6	-4	1	-3	-4	5	15
8	2	A	13	20	30	33	42	41	42	33	21
8	3	C	35	31	36	29	43	38	38	38	36
8	3	O	22	11	6	-4	1	-3	-4	5	15
8	3	A	13	20	30	33	42	41	42	33	21
9	1	C	35	31	36	29	43	38	38	38	36
9	1	O	22	11	6	-4	1	-3	-4	5	15
9	1	A	13	20	30	33	42	41	42	33	21
9	2	C	35	31	36	29	43	38	38	38	36
9	2	O	22	11	6	-4	1	-3	-4	5	15
9	2	A	13	20	30	33	42	41	42	33	21
9	3	C	35	31	36	29	43	38	38	38	36
9	3	O	22	11	6	-4	1	-3	-4	5	15
9	3	A	13	20	30	33	42	41	42	33	21
10	1	C	35	31	36	29	43	38	38	38	36
10	1	O	22	11	6	-4	1	-3	-4	5	15
10	1	A	13	20	30	33	42	41	42	33	21
10	2	C	35	31	36	29	43	38	38	38	36
10	2	O	22	11	6	-4	1	-3	-4	5	15
10	2	A	13	20	30	33	42	41	42	33	21

10	3	C	35	31	36	29	43	38	38	38	36
10	3	O	22	11	6	-4	1	-3	-4	5	15
10	3	A	13	20	30	33	42	41	42	33	21

SUBJECT	NAME	SEX	AGE
1	JOHN DOE	M	28
2	KIM SMITH	F	25
3	MIKE JONES	M	35
4	SALLY JOHNSON	F	30
5	JOE MICHAELS	M	20
6	LISA SHORT	F	26
7	TOM LONG	M	34
8	SARAH PARKER	F	24
9	FRED TURNER	M	39
10	JANE DOE	F	25

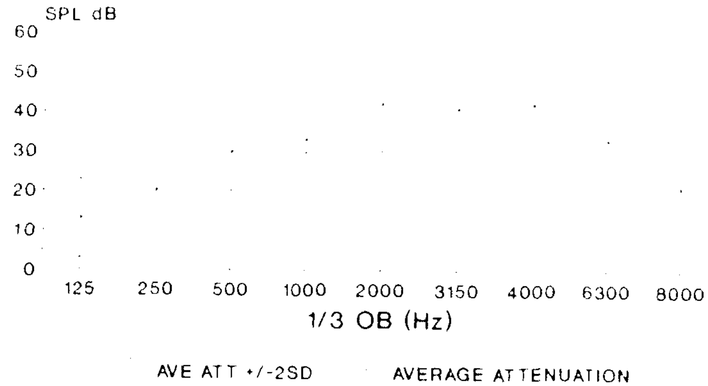
Appendix 6. Sample Hearing Protector Attenuation Report from Harvard Graphics

AAMRL/BBA

EARMUFF
MODEL: DAVID CLARK 10A RIBBED
MANUFACTURER: DAVID CLARK COMPANY INC
366 PARK AVE
WORCESTER MASS 01610
WEIGHT: 12.00oz
METHOD: ANSI Z24.22-1957
10 SUBJECTS
3 TRIALS/SUBJECT
START DATE: 1968
END DATE: 1968
PRINCIPAL INVESTIGATOR: CHARLES NIXON

REAL-EAR ATTENUATION

DAVID CLARK 10A RIBBED



REAL-EAR ATTENUATION DATA

1/3 OB	125	250	500	1000	2000	3150	4000	6300	8000
MEAN	13	20	30	33	42	41	42	33	21
SD	5.00	4.00	5.00	5.00	6.00	5.00	6.00	8.00	7.00
M-2SD	3.00	12.00	20.00	23.00	30.00	31.00	30.00	17.00	7.00

'C-A VALUES

-2 TO 0	1 TO 3	4 TO 7	8 TO 12	12 TO 19
21	19	16	13	8

'NRR= 17

'H 29 'M = 20 'L = 11

'CALCULATED USING MEAN ATTENUATION - 2 X SD

REFERENCES

1. AF Regulation. Hazardous Noise Exposure. 161-35, Department of the Air Force, Washington DC, 9 April 1982.
2. ANSI (1984). Method for the Measurement of Real-ear Attenuation of Hearing Protectors. S12.6-1984, New York, NY.
3. EPA(1979). Noise Labeling Requirements for Hearing Protectors. Federal Register, vol. 42, No. 190, 40CFR Part 211, 56139-56147.
4. ISO/R 226-1961. Normal equal-loudness contours for pure tones and normal thresholds of hearing under free field listening conditions.
5. Lundin, Rune. The HML Method: An Acceptable Procedure for Rating the Attenuation of a Hearing Protector. Proceedings of the Institute of Acoustics, Vol 9 Part 7, Bilsom International, Fountain House, Odiham, Basingstoke, 1987.
6. Knudsen, Vern O. and Harris, Cyril M. Acoustical Designing in Architecture. USA: American Institute of Physics for the Acoustical Society of America, 1978.
7. Kroes, P., Fleming, R., and Lempert, B. List of personal hearing protectors and attenuation data. HEW Publication No (NIOSH) 76120, NTIS No PB267461, 1975.

Fig. 1. Measurement Chamber Structural Alterations

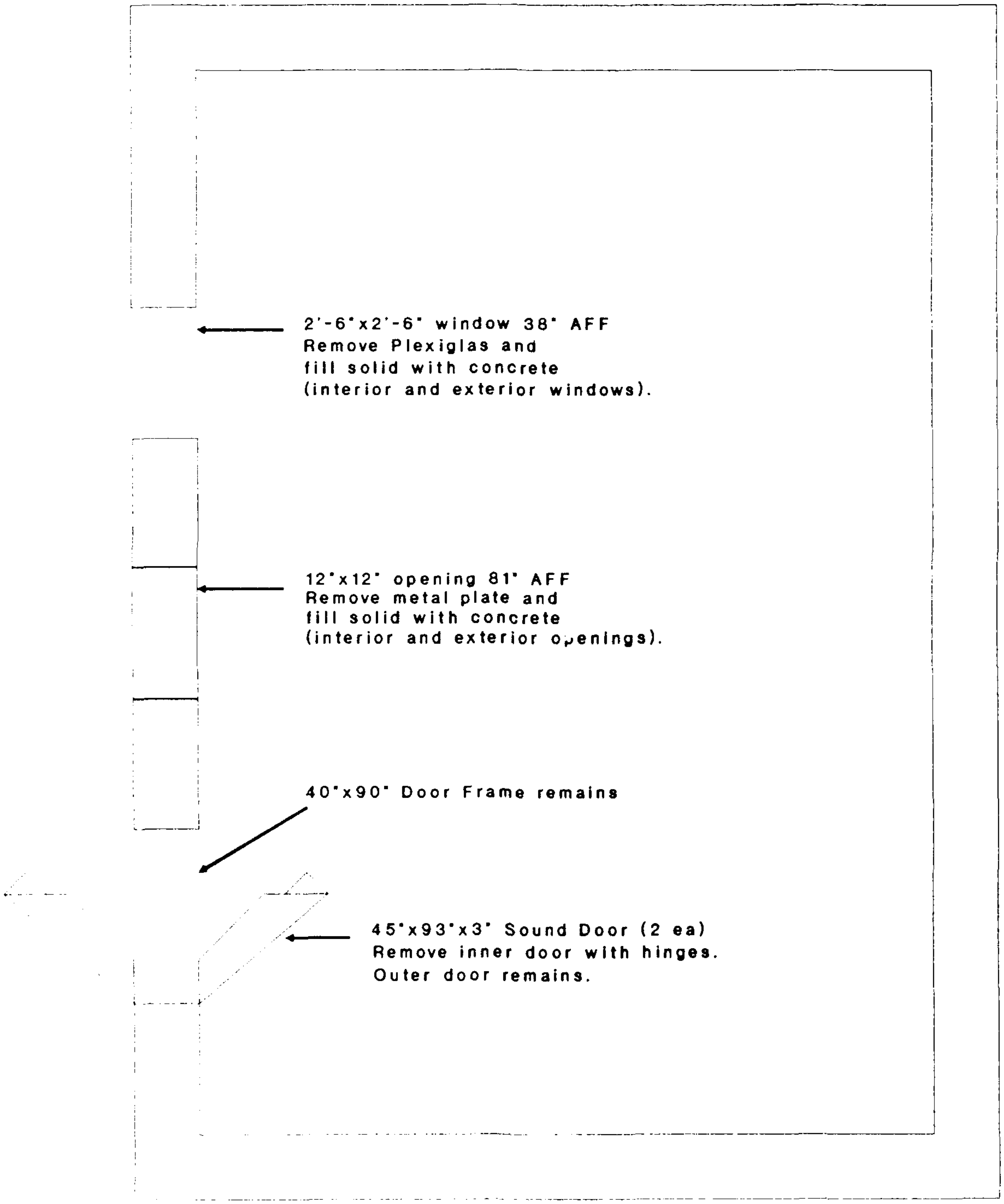


Fig. 2. Measurement Chamber Mechanical Alterations

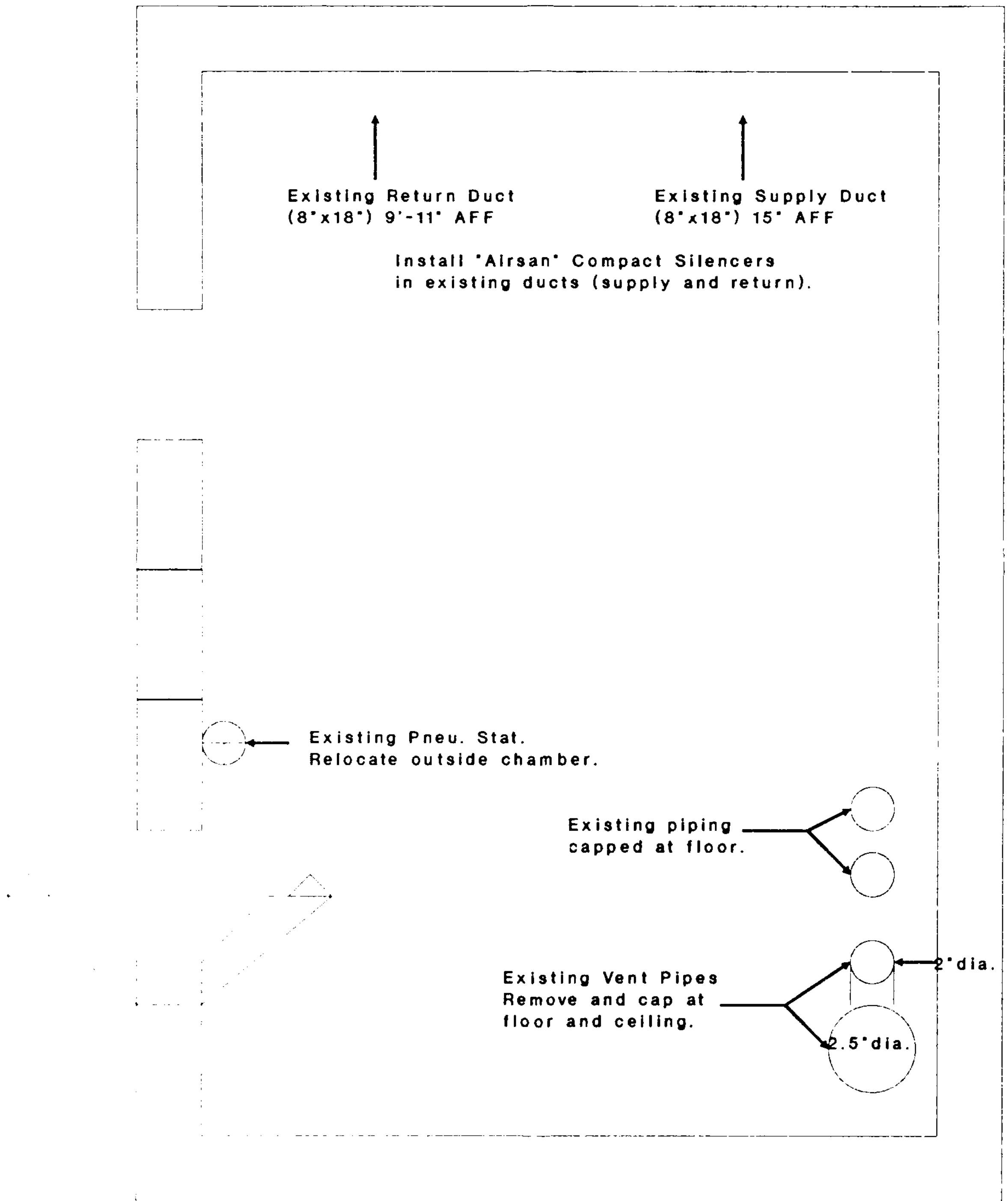


Fig. 3. Measurement Chamber Electrical Alterations

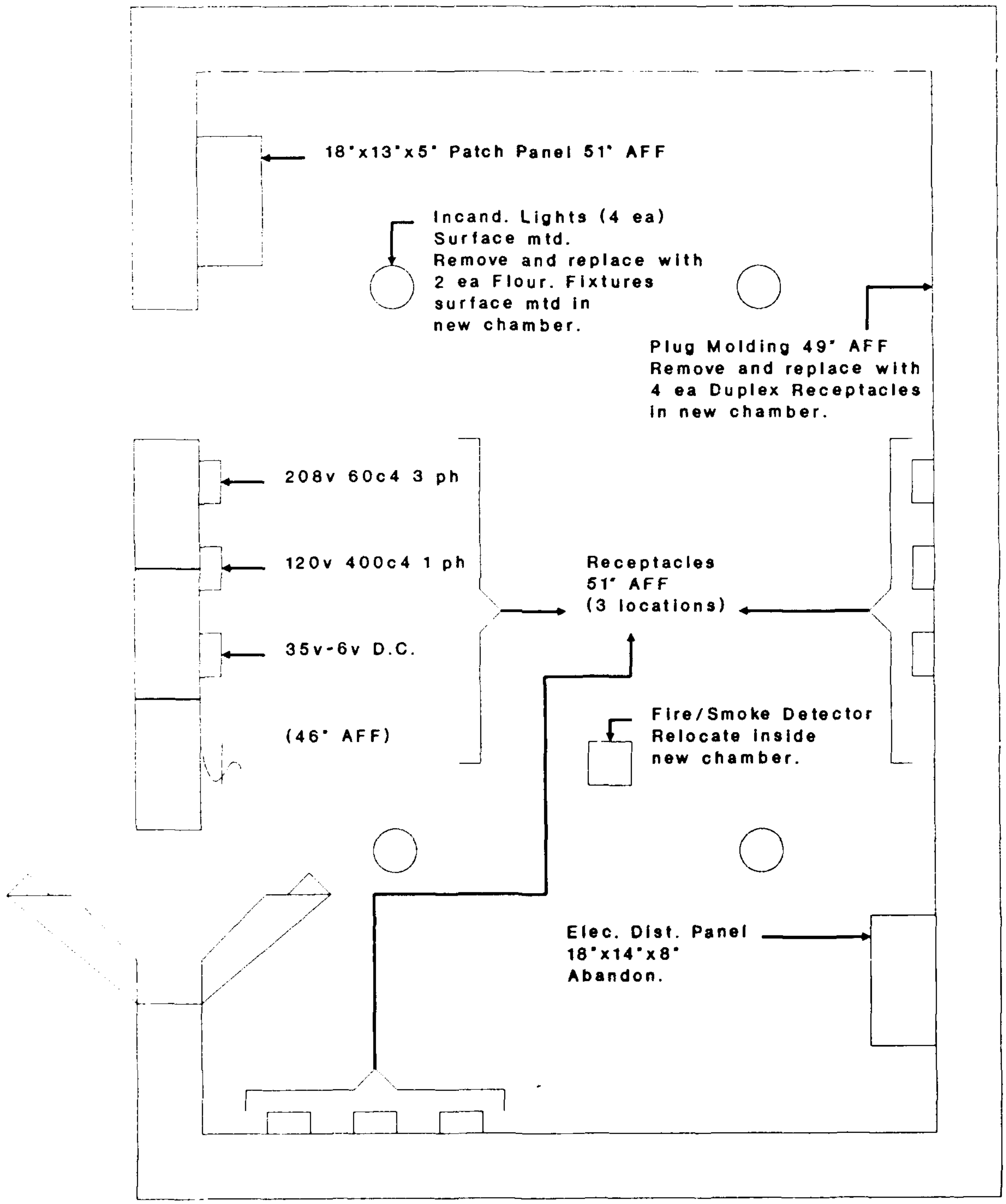


Fig. 4. Measurement Chamber Framing Detail

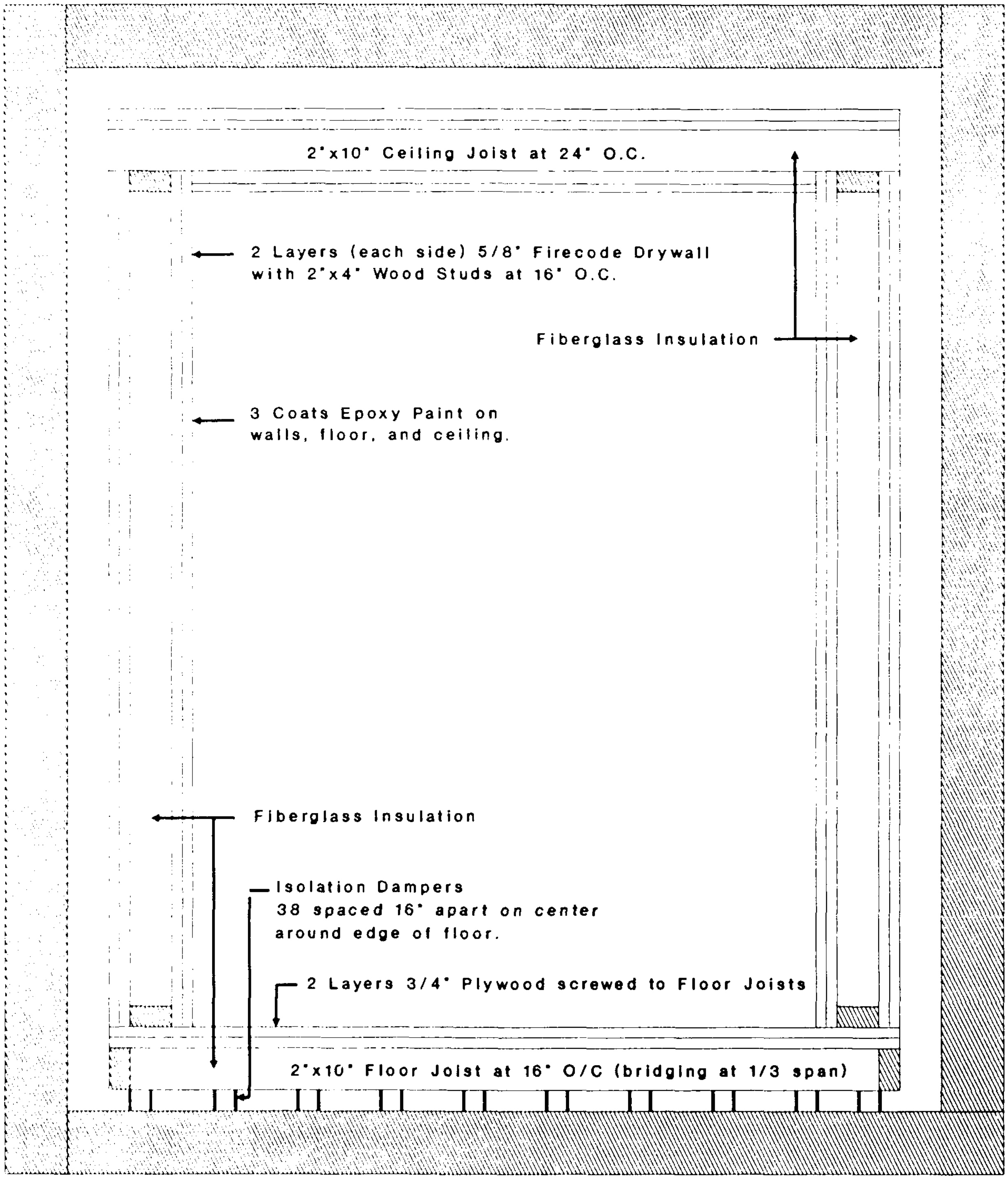


Fig. 5. Measurement Chamber Floor Framing Detail

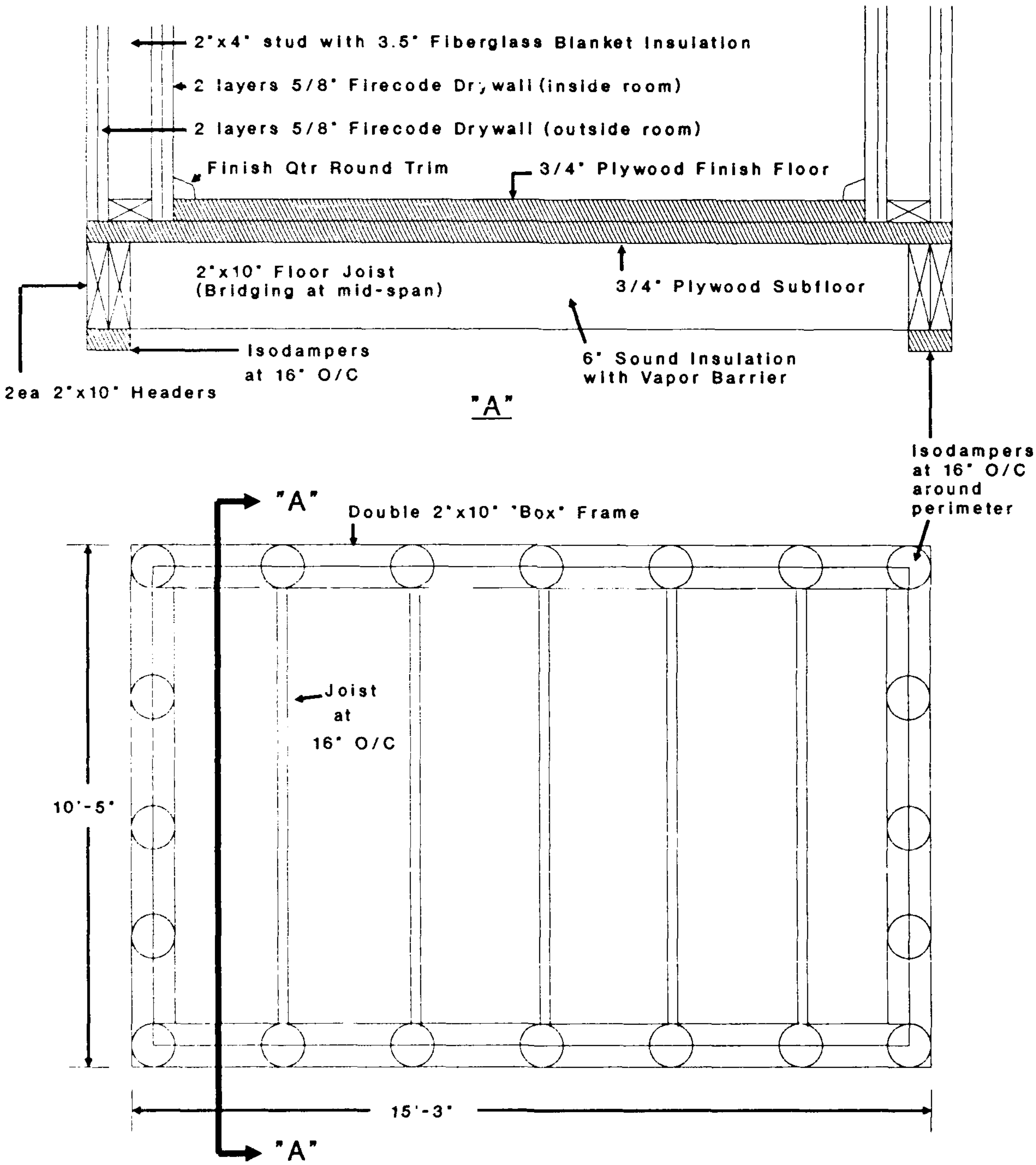


Fig. 6. Measurement Chamber Ceiling Framing Detail

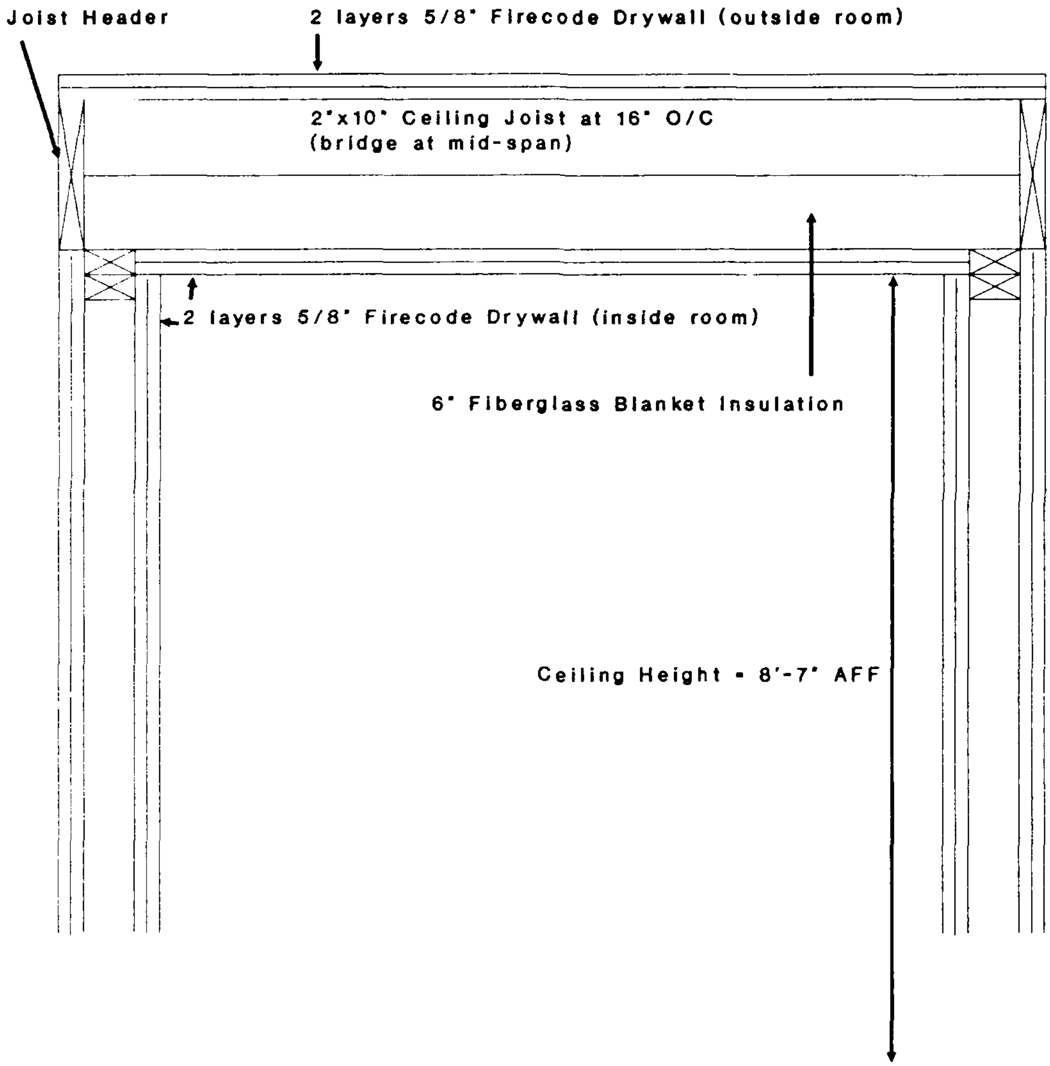


Fig. 7. Measurement Chamber Door Framing Detail

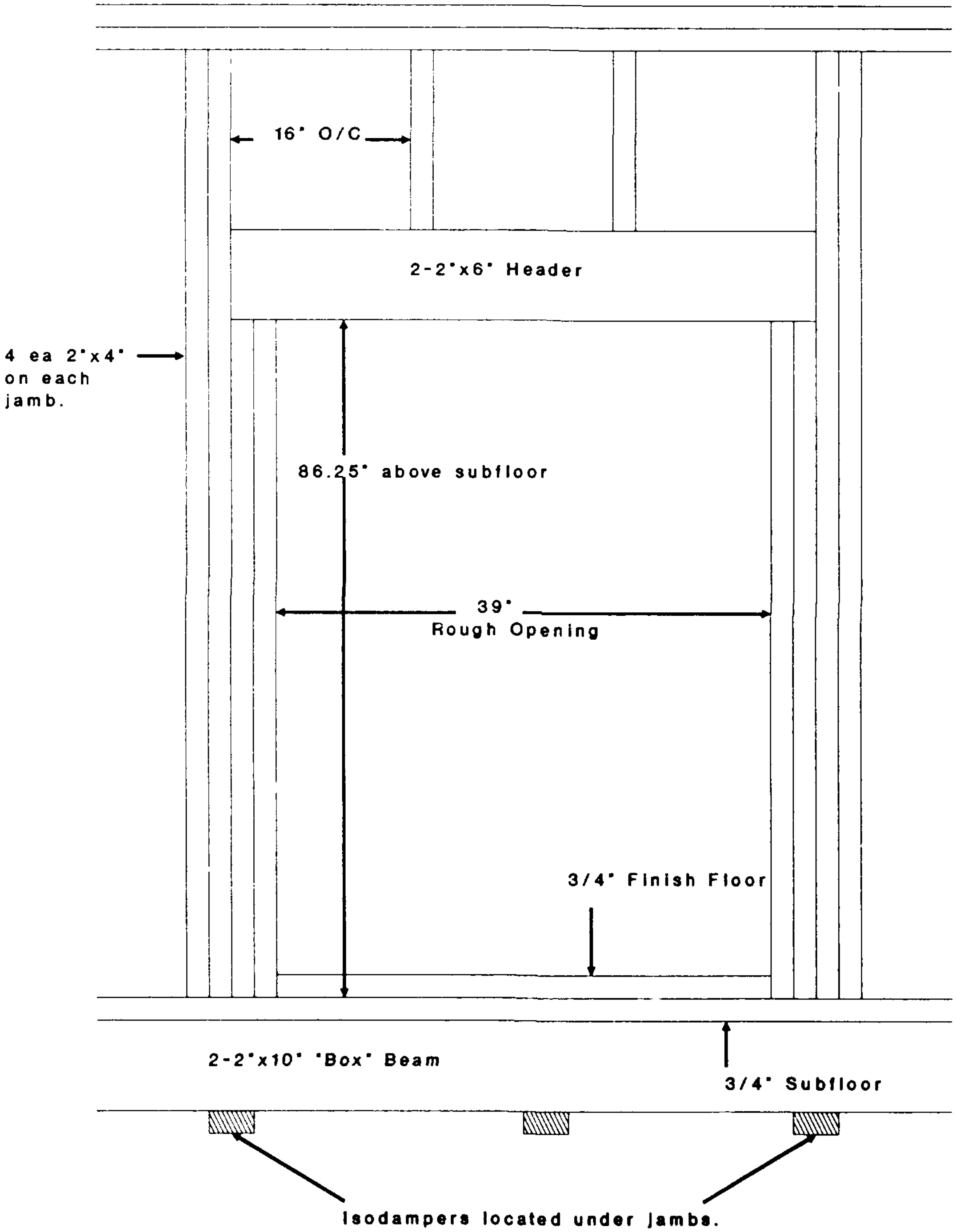


Fig. 8. Measurement Chamber New Work Detail

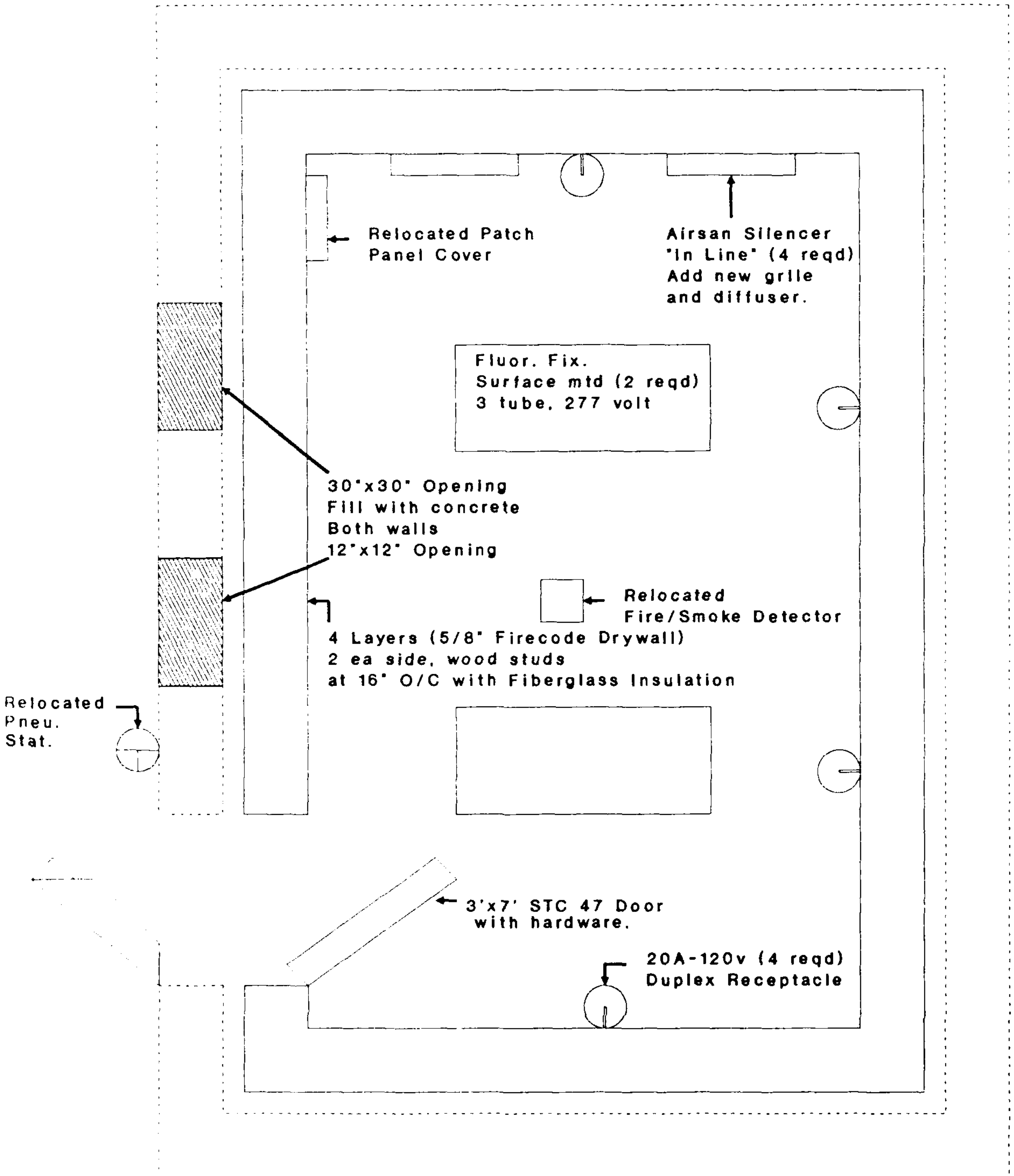


Fig. 9. RATS Measurement System Block Diagram

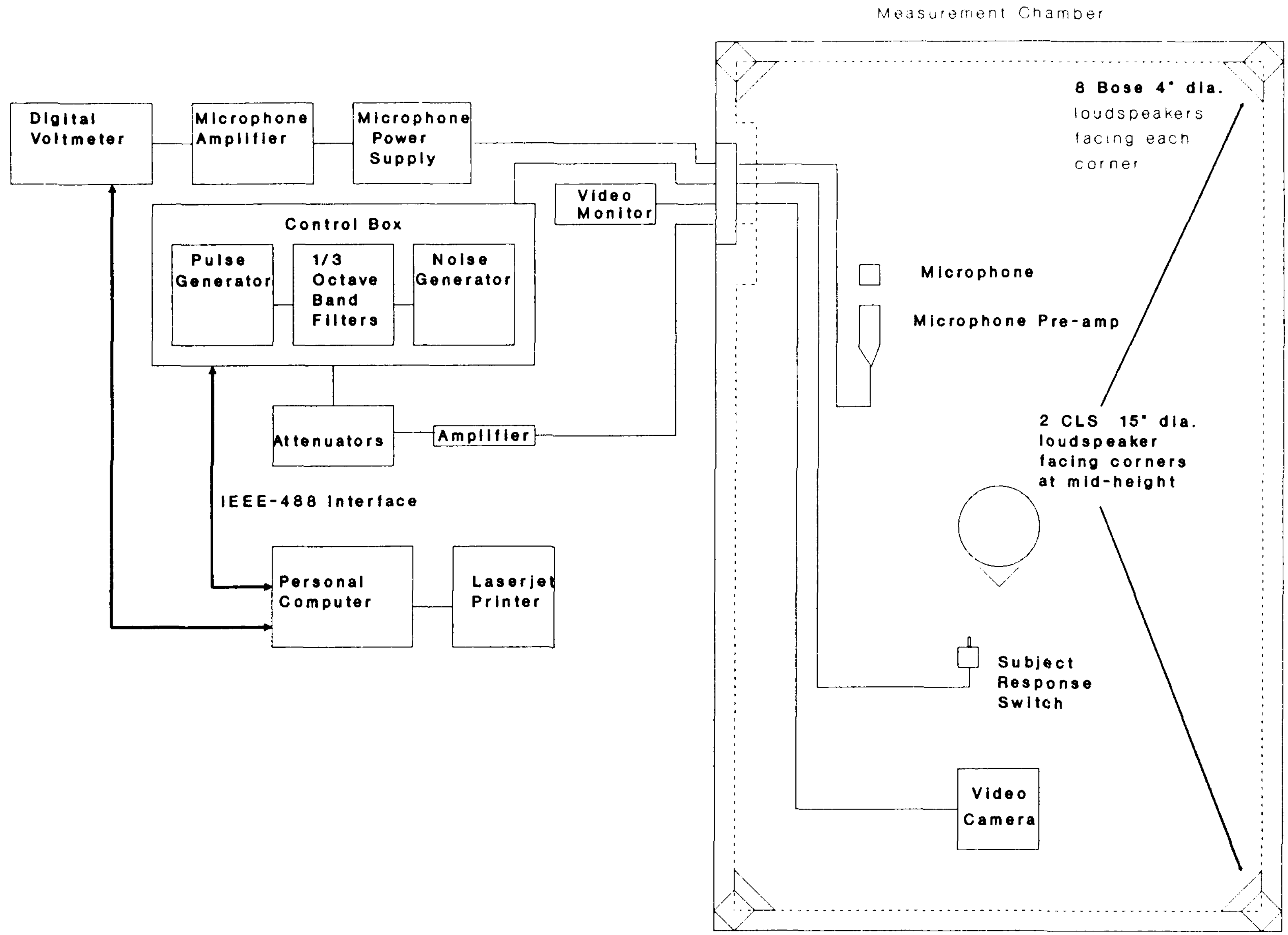


Fig. 10. Ambient Noise Measurement Block Diagram

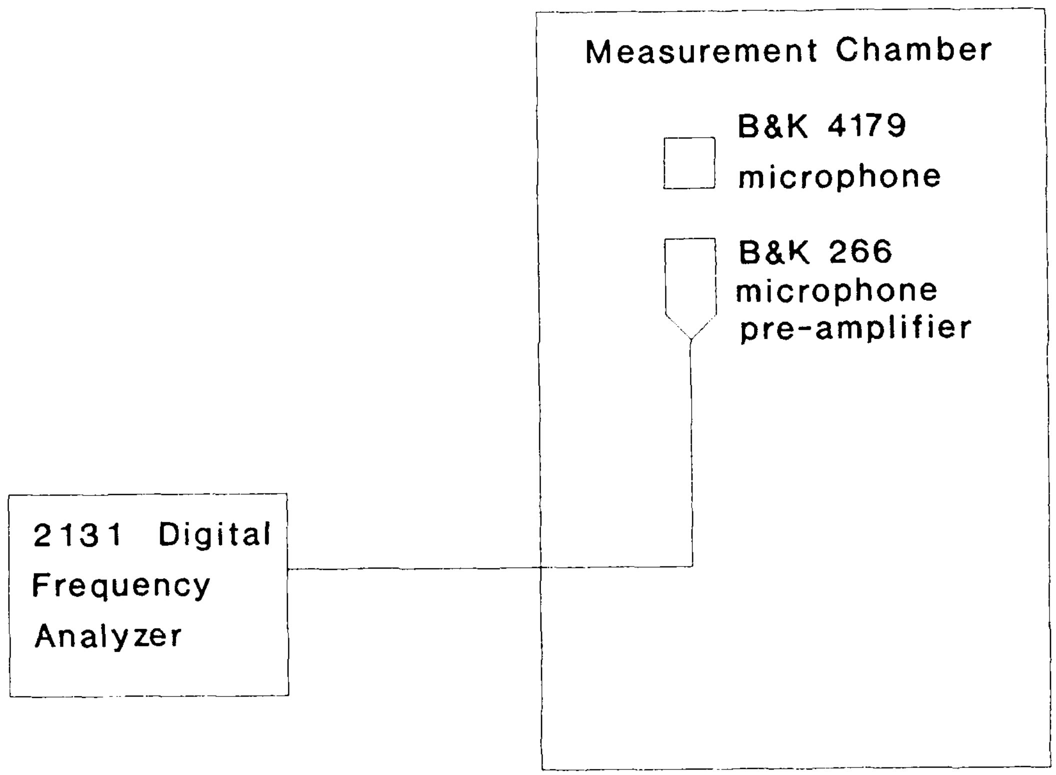
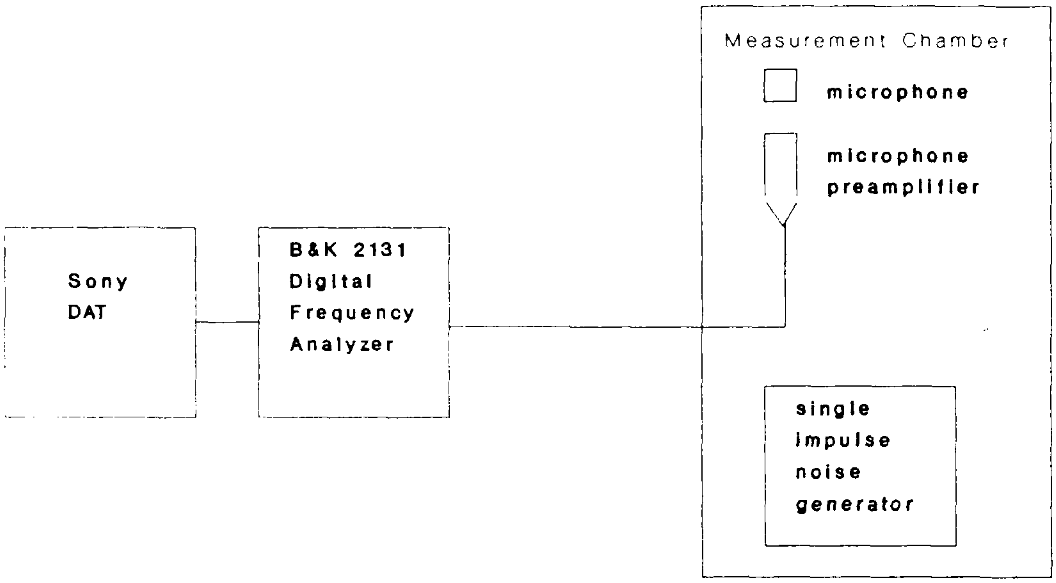
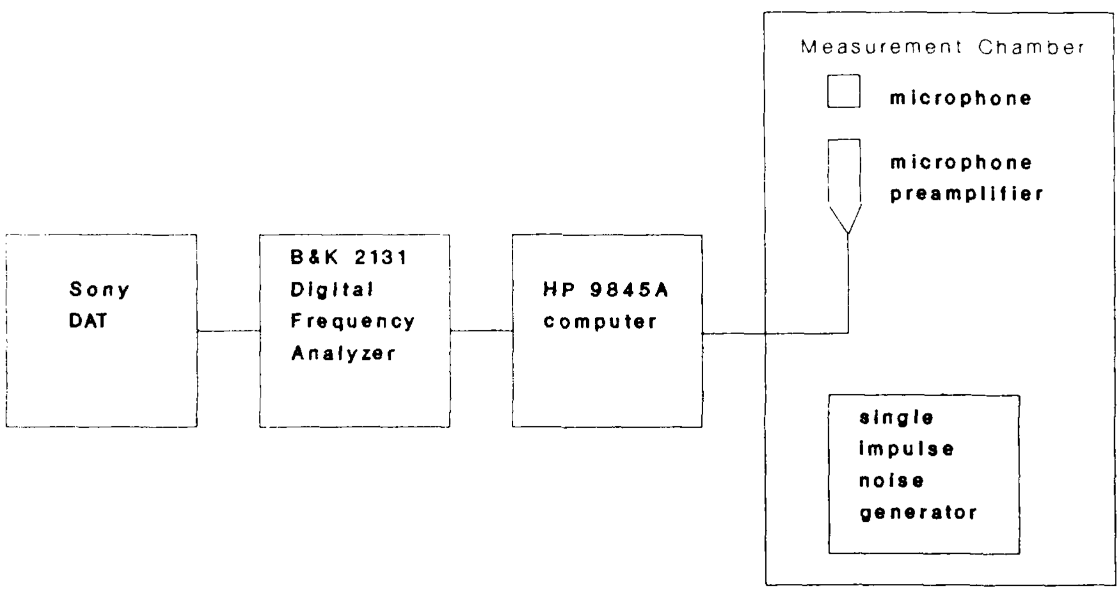


Fig. 11. Reverberation Time Measurement Block Diagram



A. Record single impulse noise.



B. Playback and analyze single impulse noise.

Fig. 12. Cardioid Microphone Calibration

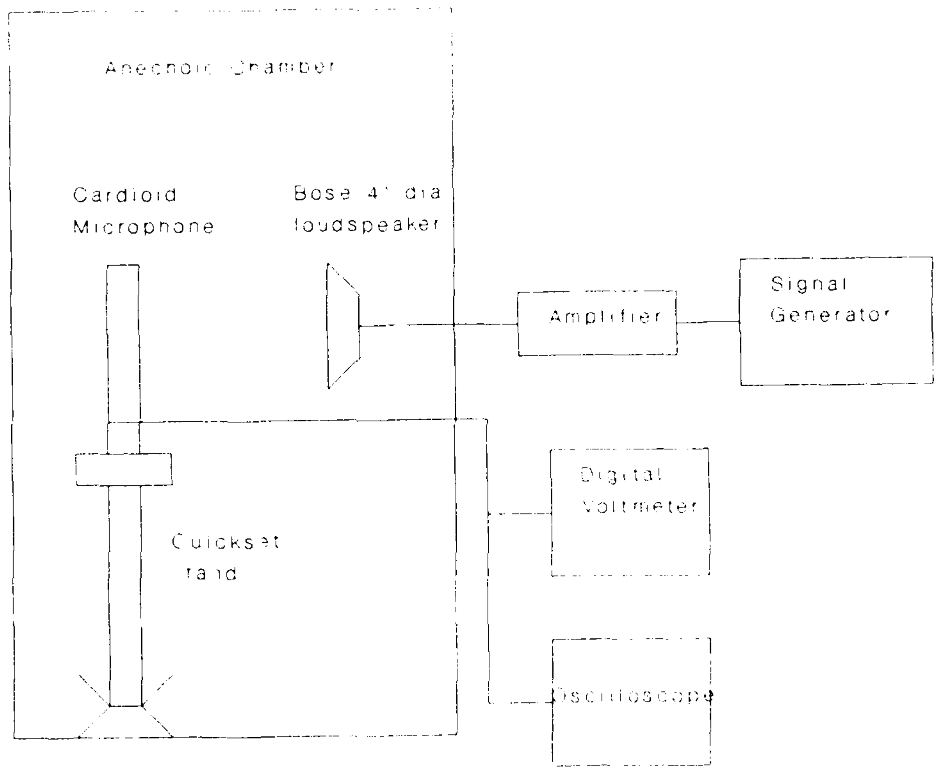


Figure 13. Loudspeaker Sound Pressure Level Output Block Diagram

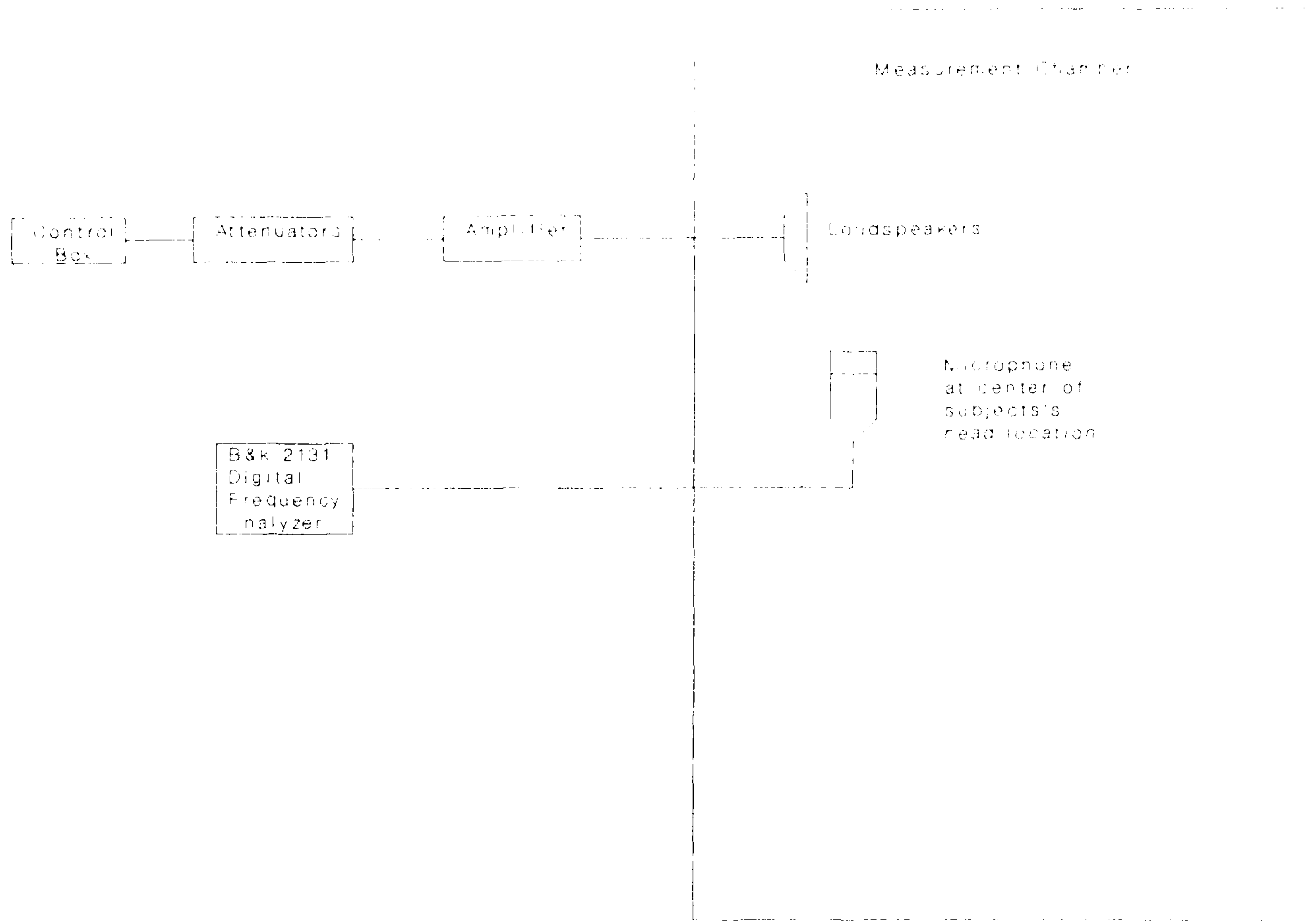
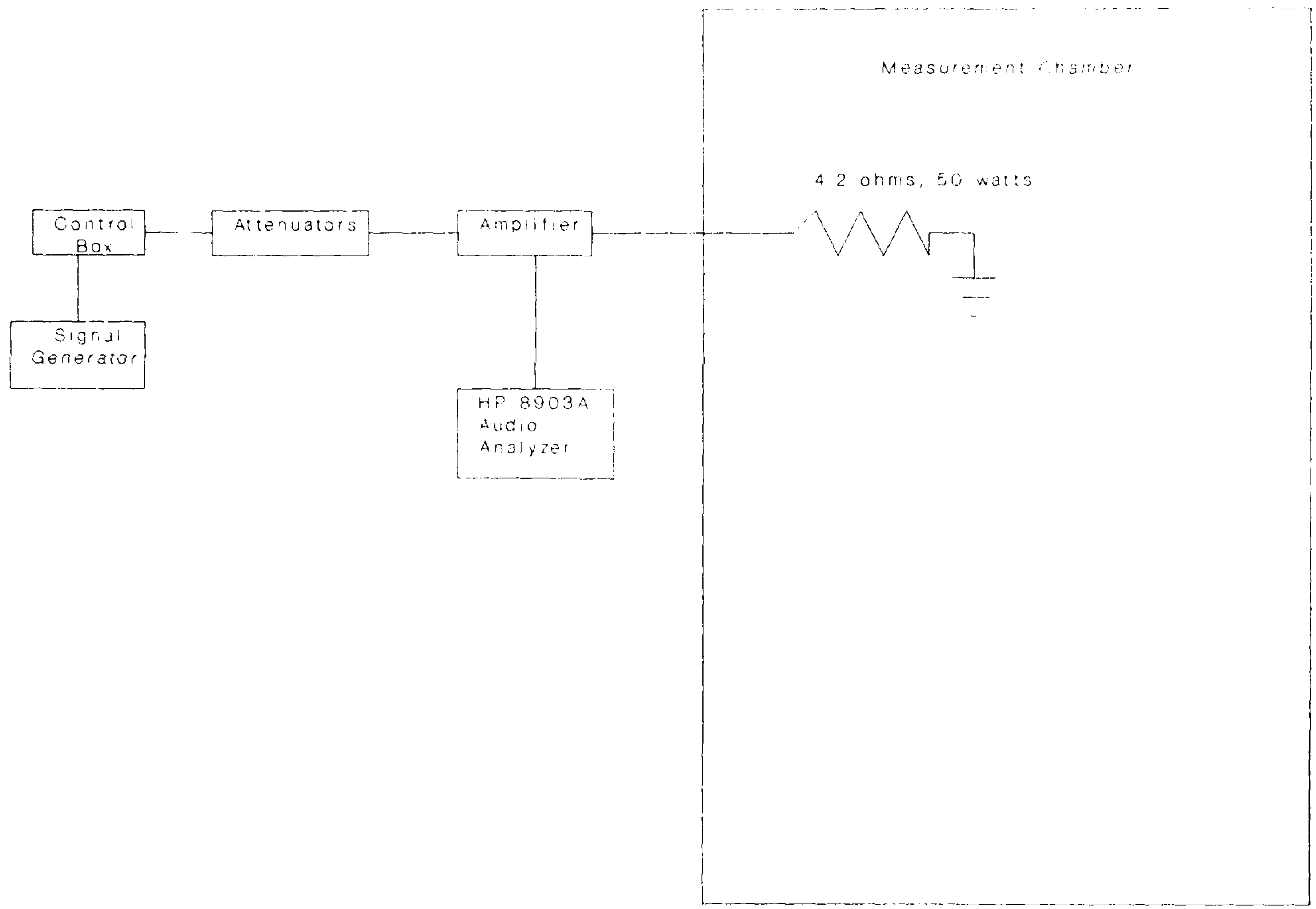


Figure 14. Total Harmonic Distortion of Measurement System Block Diagram



☆U.S. Government Printing Office: 1991 — 648-018/40214